OPTIONS FOR IMPROVING IRRIGATION WATER ALLOCATION AND USE: A CASE STUDY IN HARI ROD RIVER BASIN, AFGHANISTAN

by

Ahmad Faisal Basiri

A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Engineering in Water Engineering and Management

Examination Committee: Dr. Sylvain Perret (Chairperson)
Dr. Mukand S. Babel
Dr. Roberto S Clemente
Dr. S Ranamukhaarachchi

Nationality: Afghan
Previous Degree: Bachelor of Science in Civil Engineering
Herat University, Civil Engineering Faculty

Scholarship Donor: Norwegian Government

Asian Institute of Technology
School of Engineering and Technology
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ABSTRACT

This study investigates cropping system options in context of irrigation water scarcity. It aims at improving irrigation water allocation with the objectives of maximizing net economic return and calories production, and minimizing selected production factors. CWR and IWR for all practiced crops are estimated for the case study area based on local climatic and cropping system information. Current field situation, as per farmers' practices and water availability, is quantified in terms of demand and supply, and compared with the actual crop water needs. Different scenarios are tested including different possible cropping systems under optimal and sub-optimal water supply.

CROPWAT model was used for calculating CWR, IWR, and for developing irrigation scheduling, to quantify the yield reduction for the practiced crops during water shortages time. The gross irrigation requirement is calculated on the basis of different irrigation efficiencies with 10-day time step in the study area for all practiced crops. Results show that 10% improvement in irrigation efficiency will result in saving of average 21.4% gross irrigation requirement (GIR) for each practiced crop in the study area. Further, based on relative water supply (RWS) calculation, July, August, and September are the months during which crops are suffering from water shortage, with deficit amounting to 60, 70 and 50 % respectively, compared to what is required.

Simple optimization model is developed using linear programming with various constraints, to identify the cropping system options, through the maximization of net economic return (NER) and calorie production, and minimization of fertilizer and crop labor requirements. The results show that eliminating crops that consume more water and provide less economic and energy outputs is the most suitable option, and may highly improve over all benefits. Current farmers' strategy proves only suitable for maximizing calorie output.

The overall finding of this study can be used to support the decision making and result demonstrate good guidelines for the planners; it can be helpful for farmer to take decision on adjustment of their cropping system according to their demand (Max NER, Max Cal). Study shows that deficit irrigation and area reduction are not the best options which are currently adopted by farmers based on lower NER, but to keep all crops with deficit irrigation shows a higher calorie output which, obviously help for food security. The study provides a good opinion of achieving higher NER, optimal irrigation supply for selective cropping system and less diversification with the limited water availability. Understanding of CWR, IWR, and the irrigation scheduling during the shortage months help farmers to take the right decision for preventing any yield reduction in their farm.

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List of abbreviations

ADB	Asian Development Bank
CWR	Crop Water Requirement
Ea	Irrigation Efficiency
ET	Evapotranspiration
ERAIN	Effective Rainfall
FAO	Food and Agriculture Organization
FC	Field Capacity
GIR	Gross Irrigation Requirement
I	Irrigation
ICARDA	International Center Agriculture Research in Dry Area
R	Rainfall
IWR	Irrigation Water Requirement
SCS	Soil Conservation Service
SWD	Soil Water Deficit
NER	N Economic Return
FWS	Field Water Supply
NB	Net Benefits
AWS	Available Water Supply
OWS	Optimal Water Supply
GW	Groundwater
NER	Net Economic Return

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Water is a precious element that sustains the life over the earth. To protect this precious element from vulnerability we have to consider effective management for water resource. To utilize this vulnerable resource carefully one has to take into account irrigation agriculture water requirement, because irrigation agriculture utilizes about 70% of water extract worldwide (UN Water, 2006). Further, today up to 95 percent of available water is used for irrigation agriculture in several developing countries. For example Afghanistan is a country where 99% of water is used for irrigation agriculture (ICARDA, 2002). Irrigation agriculture plays a crucial role in determining the future food security, poverty reduction and economical growth in most Asian countries, thus effective management is an important issue in irrigation system.

The main purpose of an irrigation system is to maximize crop production to improve economic growth and alleviate the hunger and poverty in the country. Therefore, water needs to be distributed efficiently, for the crops at the right time with an effective quantity. Efficient water allocation for crops can result in saving water, increasing the cultivated land area to some more extent, or else in using that amount of saved water for other economic and social purposes such as domestic and industrial use. In order to optimize water use and crop productivity, one has to improve the water resource allocation optimally in a water limiting condition region (arid and semi arid), improve irrigation scheduling, and establish crop water needs, which are influenced by the rate of water used with the crops, evapotranspiration (ET) and other losses such as soil retention characteristic.

According to ICARDA (2002), economical consideration should be taken into account for irrigation water management in Afghanistan, whenever water availability is matter of concern. A proper management would be helpful to economize water with the consideration of a right decision on the allocation of land and water based on water availability, reliability and income through crop production.

Therefore, a study is needed to address the problems as to how to make the best use of limited water available, while maximizing economic return to water use. This requires evaluation of crop water requirement, irrigation water requirement, irrigation scheduling, cropping system and crop budget.

1.2 Rationale of the Study

Economic development in Afghanistan is highly depended on irrigation agriculture, though most parts of Afghanistan have limited water resources and past records of severe draught which may have it back in the future, people do not make efficient use of what is available, farmers do not consider actual crop water requirements. Irrigation application is based on the dry visual feature of field surface or recalling the last irrigation applied to the field, which is the proof for the lack of farmer's knowledge on crop water requirement and irrigation water requirement. And the irrigation scheduling techniques are still mainly based on availability of maximum quantity of water which a farmer can get. Hence present irrigation patterns of farmers include a tendency to over irrigate or giving extreme shortage, which cause the insufficient situation for the crops (Asad, 2002).

Furthermore, the distribution of water adequately to match the crop water demand at different stages of growth is a vital issue, which is not much considerable in Afghanistan due to unreliable irrigation supplies, inefficient water management, and lack of understanding of how the water should be managed and applied. According to ICARDA (2002) scarcity of water is the most crucial constraint against agriculture development in Afghanistan. To address the solution for improvement in water availability and value of the issue, this research study is focused on the improving of irrigation water allocation and use. According to Asad's recommendation in context of Afghanistan, irrigation water management for a sound use is the primary issue has to be matter of concern (Asad, 2002). This study help for more beneficial planning based on maximum water saving to expand irrigation area, and reduce the poverty through the maximizing the net benefits and calories production with respect to cropping system. Herewith an effort has been done on a case study basis in the Jui Nau irrigation system in Herat Afghanistan to find out solutions for current problems.

1.3 Objective of the study

The overall objective of this study is to investigate cropping system and water use options to improve irrigation water allocation and use in context of short supply, on a case study basis
The specific objectives include:

- Assessment of CWR and IWR in the case study area for various crops, using CROWAT model, and identifying impact of irrigation efficiency on GIR.
- Quantifying current field condition (farmers strategy to counter water scarcity) and compare with the actual crop water needs,
- Optimization of cropping system under limited water supply towards specific objectives, particularly maximizing NB, calories production, and minimization of selected production factors.

1.4 Scope and limitation of the Study

The study considers the application of CROPWAT model to first estimate crop water requirement (CWR), irrigation water requirement (IWR) and identifying impact of irrigation efficiency on GIR. Secondly, monthly irrigation water demand for practiced crops is estimated in the case study area using the model. Thereafter, based on the structured questionnaire and field observation, canal water supply is estimated for understanding current field situation on the account of water demand and supply. Further, farmer's strategies are explored to counter water shortages. Thirdly, for investigating possible cropping system on account of optimal and sub-optimal water supply, different management scenarios have been tested as follows;

- Reducing area of all crops towards optimal supply of water, and IWR satisfaction,
- Eliminating some crops towards optimal supply of water, and IWR satisfaction,
- Keep all crops but with sub-optimal supply of water,

The scenario results have been evaluated from economic and calories production point of view. Quantitative System for Business (Win-QSB), which is an optimization technique tool that use simplex algorithm, has been used to identify the cropping system option, through the maximization of net economic return (NER), calories production, and minimization of fertilizer and crop labor requirement.
The major constraints in this study are listed as below

- Groundwater contributions for irrigation in the study area is beyond the scope of this study
- Water Quality for irrigation purpose is assumed to be appropriate and homogenous.
- Field test for soil is another constraint due to budget limitation.

CHAPTER 2

LITERATURE REVIEW

This chapter includes a brief description about Afghanistan water resource system, and other necessary information for understanding the general idea of irrigation, crop water requirement, irrigation scheduling, optimal cropping pattern, production cost, NB, gross income, and the models which are used for this study.

2.1 Afghanistan Water Resource System

Afghanistan is situated in the central Asia. The countries located in the north of Afghanistan are, Tajikistan, Uzbekistan and Turkmenistan and sharing boundary with each country around 1206km, 137Km and 744km respectively .In northeast it is bounded by China sharing a boundary of about 96Km. Iran and Pakistan are located in the south and east of the country by sharing a boundary of 925km with Iran and 2412km) with Pakistan.

Rainfall In the country varies each year in different parts of Afghanistan, which changes from Farah province located in south with a rainfall of 75mm to 1'170 mm rainfall in Salang located in north, so the climatic condition of Afghanistan can be said as semi arid. The rainfall usually starts form February to April the winter precipitation in the farm of snowfall is usually received in high latitudes which is essential for irrigation in summer season from June to October, the amount water received from precipitations is not adequate for rain fed agriculture activities in most part of the country (Raphy *et al.* 2004).

Fig: 2.1. Afghanistan map, www.infoplease.com

According to study conducted by ADB (2008), the total cultivated land area in the country is estimated about 6.5 million hectares in1970. The various types of traditional irrigation system were covering around 3 million hectares of total 6.5 million hectare land area. Because of sacristy of water and lack of proper management particularly lack of efficient operation and maintenance the irrigation systems has been seriously deteriorated consequently the irrigated land has been declined to 2 million hectare. Around 80% of total irrigation systems in the country are traditional irrigation system which are built, maintained and operated by local communities. The irrigation systems in the past was satisfactory up to some extent but the recent turnover have vanished or severely damaged the infrastructures, maintenance and operation and other related services. To prevent more damage it is important to rehabilitate and reconstruct the irrigation systems in the country.

The economy of the country is not well developed yet. Around 80% population is settled in rural areas and highly reliable on agriculture and livestock farming. The economy of the country is traditionally based on agriculture sector which is the highest contributor to gross domestic products comparing to the other sectors. Agriculture is the only sector employing around 65 % to total labor force. As Afghanistan is an agrarian country therefore it is entirely reliant on agriculture sector, the water management and irrigation management issues are very important to be considered. (Ministry of Energy & Water) Irrigation productivity for irrigated land area is much higher than rain-fed land, base on a survey in 1978 almost 80% of wheat and 85% total crops produced on irrigation lands. On the other hands at the present water use efficiency is very low merely about 15 to 30 % (Asad, 2002).

In Afghanistan water management issues are very important in order to maintain food security and sources of income of huge number of people in rural areas (Rout, 2008). According to Asad (2002), almost 99% irrigation land area irrigation water management is of crucial importance. Because traditional irrigation systems covers around 99% or total 2.3 million hectare irrigated land area of which merely 90% area is coming under the coverage of informal traditional irrigation systems, constructed, operated and maintained by local people (Asad, 2002). Based on FAO report the developed irrigated land was around 1.44 million hectare which can support double cropping of total 2.63 million hectare irrigated land in 1978 (FAO, 1997).

Most of irrigation systems in Afghanistan are traditional irrigation system, the water allocation and distribution is based on traditional water right system. The amount of irrigation water tapped in canal irrigation systems from different rivers is around 84.6 %, the water tapped form Karezes was noted around 7 % whereas, water tapped from springs and arhats (shallow tube wells) are 7.9 and 0.5 % respectively (Aini, 2007).

Aini (2007) reports based on information from FAO and the Ministry of Energy and Water under the Afghan government that 80 % of Afghanistan water resources highly dependent on amount of precipitation received in a year particularly snow melt in the highland above 2000 m, without contribution of ground water. The amount of water in a year received in highland from snow melt is estimated around 150,000million cubic meter and quantity of water received from rainfall is only 30000million cubic meter in the country. A total of 180,000milion cubic meter received from both rain and snow fall. Merely 15% of total runoff contributes to the ground water discharge (Aini, 2007). According to hydrology department of Ministry of Energy and water based on surface irrigation water, Afghanistan is classified in to five main river basins and into five main non drainage areas.

- The Amu Darya Basin in the north of the country flowing from east to west and contributing around 48,120 million cubic meter which is 57% of total surface water in over all country.
- The Hari Rud River Basin flowing toward the west, then north and entering Turkmenistan, and contributing 3,060 million cubic meter which is around 4%of total surface water in Afghanistan.
- The Helmand River Basin flowing toward the south-west and ponds in Hamun-i-Sabiri, contributing 9,300million cum, which is 11% of total surface water in Afghanistan
- The Kabul River Basin flowing toward the east and joining the Indus River in Pakistan, Contributing 21,650million cum, t hat is almost 26% of total surface water over all the country.
- The north flowing river basins that either disappear inside or outside of the country. This river basin contributing around 1,880 million cum, t hat is almost 2% of total surface water over all the country.

2.2 Water Resource Problems in Context of Afghanistan

Water is a main problem both in urban as well as in rural areas because of shortage of water, lack of management and deterioration of water supply schemes. According to FAO news regarding the water issues, water in context of Afghanistan "Water is the lifeblood for the people of Afghanistan, not just for living but also for the economy" more than twenty years of war have damaged much of irrigation systems, infrastructure and other water supply schemes, these are very essential for the agriculture sector economy. The proper management and development of water resources in Afghanistan are essential for sustainability in economic growth.

The negative effect on efficiency of irrigation schemes and the capability of communities to maintain and sustain these in traditional methods are the outcomes of around thirty years of war and social conflict. According to FAO (2003) estimation, due to social conflict and severe drought, nearly half of the irrigated land area needs urgent rehabilitation.

In order to overcome the problem of water resource in the country and increase agricultural productivity and assure sustainability of agriculture activities practiced on irrigated land, the strategy should be concentrated which focus on enlargement of water capital and assure efficient utilization of water. "For the formulation of strategy for the rehabilitation of irrigation systems, a comprehensive database and information systems should be established. This is absolutely necessary for the accurate and up to date assessment and spatial locations of the rehabilitation work need to be undertaken'' (Asad, 2002).
Basically Afghanistan has limited water resources, which does not make well-organized utilization of amount of available water. Farmers are lack of knowledge of actual irrigation water needs and irrigation scheduling techniques are still mainly based on the amount of

maximum water available for a farmer. Therefore present irrigation methods of farmers show a tendency to over irrigate, while the reverse should be accomplished, (Asad, 2002).

Currently very little is known regarding water utilization efficiency in context of Afghanistan. However, due to less efficiency water allocation the production from per unit land area is low. Thus further investigation is needed to address the impact of irrigation water allocation, distribution and scheduling on different crops productivity, (Rout, 2008).

2.3 Assessment of Crop Water Requirement

Smajstrla (2002) defined crop water requirement as the total water allocated to fulfill crop's evapotranspiration demand from irrigation or precipitation hence, it does not decrease the production. Crop evapotranspiration relates to the quantity of water that is lost by evapotranspiration. It is important to verify crop water requirement in order to understanding irrigation demand in better way. Irrigation water requirement is basically understood the variation in the crop water requirements and the effective amount of available precipitation. With Irrigation water requirement we have to consider including the amount of water for leaching of soil and its adjustment for non-uniformity of water application (FAO, 1998).

The equations given below are used to estimate the "crop water requirement" (CWR) which is basically equal to the crop evapotranspiration in normal considerations. Having in mind, there are no restraint placed on crop growth like crop density, diseases, water shortage, insects and weeds and salinity pressures. In order to practically compute the actual crop evapotranspiration (ETc), firstly it requires estimating potential or reference Evapotranspiration after that, imposing the proper crop coefficients (Kc).

$$ETc = Kc \times ETo \quad \text{(Eq.1)}$$

ETc = Crop evapotranspiration in mm/day
Kc = crop coefficient, dimensionless
ETo = Reference crop evapotranspiration in mm/day

To keep out crop water stress in arid climatic conditions, irrigation and the amount of rainfall must be enough to meet the crop's ET requirement. It means that for any time period throughout the growing season of a crop, the "irrigation water requirement" (IWR) is the quantity of water which is not efficiently provided by rainfall:

$$IWR = (ET - ER) \quad \text{(Eq.2)}$$

IWR= Irrigation Water Requirement needed to satisfy crop water demand, (mm)
ET= Evapotranspiration (mm)
ER = Effective Rainfall (mm)

Irrigation water requirement is the quantity of water that has to be present at crop root region for the crops utilization. To make available (IWR) usually some water wastage happen while moving it from the source of water to the depth of crop root zone because of evaporation and canal percolation. Therefore, more irrigation water must be allocated than the required amount for application in depth of crop root zone. So, this new amount of water called gross irrigation requirement (GIR) which is greater than IWR and to calculate GIR we have to divide IWR by a factor which depends on the irrigation efficiency (Ea).

GIR = IWR / Ea ……………………………………………………….………… (Eq.3)
GIR = Gross Irrigation Requirement (mm)
Ea = Irrigation Efficiency (always less than one, <1, dimensionless)

The irrigation water requirement may be computed for any time period, it is usually estimated for monthly and seasonal or annual time periods.

The concept of a water balance can be defined as an estimation of total amount of water which enter and leave 3D space due to a specific period of time. Burt (1999) mentioned that water balance is not merely limited to irrigation, rainfall, or groundwater. It has to enclose all water which enter and leave the spatial boundaries.

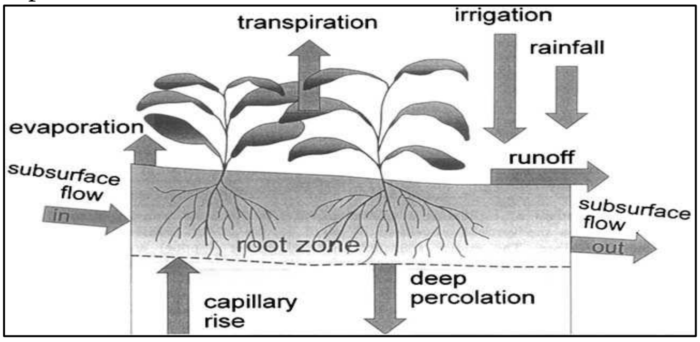


Fig.2.2. Water balance in root zone, Source: (FAO, 1998)

Smajstrla (2002) pointed that irrigation water requirement can be estimated by two ways firstly historical observation and secondly numerical models, which numerical model can be based on statistical method or on physical laws that regulate crop consumption and use.
Historical observation is a type of estimating crop water requirement, there is a need for long term record of irrigation water application and crop has been repeatedly grown in a location. This information can be useful for estimation of future irrigating demand. It can be desirable to have 20 to 30 years of record and the problem is that little such long term data base exist for computation of accurate values. On the other hand accurate historical data may be obtained from growers or irrigation system managers who may have significant field experience regarding irrigation system and crops.

Numerical models can be based on statistical applications or on physical rules that control crop water utilization and consumption. “The Soil Conservation Service” (SCS, 1970) procedure is based on a statistical regression procedure permits crop irrigation need on monthly basis, to be computed according to water-holding features of soil, monthly basis crop ET, amount of monthly rainfall received, and soil information. Application of the model is restricted to surface irrigation system and sprinkler irrigation system, it is because this model can applied for those crops cultivated on the area having deep water table present and furthermore, it can be applied to deep soils which easily drain excess amount of rainfall. Data which is required for soil storage on a typical depth of amount of water applied for a single time of irrigation and it requires assure that applied depth of irrigation water is adequate for water maintaining capacity of soil and for specific crop water requirement (Smajstrla, 2002).

To develop the capacity of management of irrigation and utilizing available water resource efficiently and effectively to meet the possible variation of cropping pattern, and making easy management of irrigation practice, it is important to be considered that irrigation management modeling for estimating the various crops water requirement, recent models which are developed through researchers implement on farm water demands with regard to the climate, plant system and Soil briefly explained as below (Sheng, 2001).

Smajstrla (1990) developed the “Agricultural Field Scale Irrigation Requirements Simulation” (AFSIRS) model that is a numerical computerized one founded simulation model based on water budget at the crop root region. This model has the capability of calculating amount of irrigation water requirement on annually, seasonal, monthly, two weeks, weekly, and daily basis. Though, a long time historical daily data of Evapotranspiration and amount of precipitation is needed for the model of the site to be simulated. Furthermore, it can estimate extreme as well as mean values of irrigation need. In addition it needs more inputs that clarify crops, soil, components effecting irrigation requirements, as well as irrigation system (Sheng, 2001).

Sheng (2001) mentioned that “Crop yield and soil management simulation model” (CRPSM) which is used for estimation of crop production as per soil moisture content availability, different crops and climatic condition during different growing stage has been developed in 1987 by Hill et al.

A model of “Unit Command Area” (UCA) that is based partly on the idea of “Crop yield and soil management simulation model” (CRPSM) has been developed by Keller in (1987). This model is created from 2 other sub model: The “on-field sub model” and “water allocation and distribution sub model” to assess and estimate whole (UCA) water requirement and renew water equilibrium in soil on the daily basis (Sheng, 2001).

Smith (1991) developed “Decision Support System” CROPWAT for measurement of crop water requirements, irrigation requirement for rice and upland crops and reference evapotranspiration. The most recent CROPWAT version that is to say CROPWAT 4W, which was jointly formulated by the FAO, Southampton University of UK, and National Water Research Center (NWRC) of Egypt, used in a windows interface enclose to a sample water balance model that takes into account the calculation of yield reduction and water stress condition simulation which is grounded on a considerably set up methodologies for finding of crop Evapotranspiration (FAO, 1998).

To increase crop potential production by providing water for transferring water, cultivating rice at a proper time and prevent for water stress through an advance system, Chong in (1992) developed the model which has the name of Rice Irrigation Management Model (RIMOD with an improved operation management system (Sheng, 2001).

Prajmwong in 1994 originated "Command Area Decision Support Model" (CADSM) the model grounded on 3 other main sub models: firstly weather and field generation, secondly on-field –crop-soil water balance simulation and thirdly water allocation distribution (Sheng, 2001).

A genetic algorithm (GA) method was develop under the Irrigation Simulation and Optimization model (ISOM) by Kuo,Sheng-Feng (1995) for maximizing net irrigation project benefits, and to maximize irrigation allocation lands for different crops (Sheng, 2001).

2.4 Irrigation Scheduling

In most developing countries these days irrigation scheduling is just at inception level, although irrigation scheduling is one of the main managerial issues that aim for further efficient water utilization. The raises of competitions among agriculture as well as non-agriculture sectors have increased. Sustainability of irrigation schemes becomes issue of concern, because of increase in agriculture productivity demand and absence of irrigation water resource availability. Therefore water is becoming a limiting factor nearly in all irrigation projects, so these will be guidelines for effective and efficient utilization of water through many water saving techniques.

According to Chambers (1983) Irrigation scheduling can be a source of preserving water that supports to make decisions for allocation of quantity and timing of supply of water according to water requirement of different crops. It is the key concern which has the potential to assure the performance to gain sustainability in agriculture farming systems, particularly the stability, productivity, equity and (FAO, 1996).

George (2000) pointed down two question has to be answered through irrigation scheduling firstly when to irrigate the crops and secondly how much water should be applied. Irrigation scheduling quantitatively is based on three ideas, namely crop monitoring, soil monitoring and water balance technique. The manner that is based on crop monitoring, leaf water potential or canopy temperature has to be take in to account so the main restriction with this method is that the decision to irrigation is made after the crops has suffered from some amount of moisture stress. Soil moisture monitoring can be useful for irrigation scheduling but, this approach is a bit more time consuming and labor-intensive so it's not economical. A Soil water balance approach which grounded on irrigation scheduling models, computing soil water over the crops root zone. Many models are developed base on this approach for crops water requirement. And a number of computer based simulation models are develop based on this approach, which is widely approved by researchers and other professionals.

Irrigation water management generally has not received sufficient attention from schemes operators but, as struggle for water resources rises up to compound, departments of irrigation in many countries are usually searching for techniques to improve efficiency of water use. Required water management is being usually enclosed in the gorals of lot of rehabilitation projects, with computer-based irrigation scheduling viewed as a promising tool

According to Smajstrla *et al*. (2006) as the constraint of scheduling irrigations are based on plant indicators, thus irrigation is mostly scheduled based on soil water status. The procedure which is used for irrigation scheduling mentioned as below.

- Water balance approach grounded on the estimated crop water requirement rate and soil water storage.
- Through a direct measurement of soil water status based on the instrument, and
- To combine the above methods in which soil water status instrumentation is used with a water balance procedure.

The main prior to improve scheduling irrigation efficiency is required to have knowledge of the crop water requirement, root zone depth, and soil water holding capability. Researchers have introduced many techniques for irrigation scheduling for several crops. Mathematical modeling for predicting optimal crop irrigation requirement which is developed has concentrated the attention of many researchers.

Cranfield University workshop (2007) proved that irrigation scheduling with the water balance approach is grounded on calculating the soil water content, which is represented with the difference among water that has entered due to rainfall or irrigation and the quantity that has left based on losses (Conveyance, Application, Percolation and Evapotranspiration) from the soil surface and crops.

Change in water content of soil is equal to Inputs minus Outputs. If inputs are greater than outputs, in this case the soil is wetter but in inverse case which means, outputs greater than inputs, thus we will have a drier soil. It is common in irrigation to describe the soil water status in terms of a soil water deficit (SWD) instead of soil water content. The SWD can be defined as the difference among the field capacity (FC) water content and present soil water content.

A positive soil water deficit shows that soil is drier than field capacity. Therefore, the daily change in soil water deficit equals to outputs minus inputs

If inputs > outputs, it shows a less soil water deficit

If outputs > inputs, it shows a greater soil water deficit

SWDi - SWDi-1 = ETi-1- Ri-1 - Ii-1………………………………………..…… (Eq.4)
To arrange the above equation we will get
SWDi = SWDi-1 + ETi-1 - Ri-1 - Ii-1
SWDi = soil water deficit at time i
ETi = crop water use at time i
Ri = rainfall at time i
Ii = irrigation at time i

We can measure, or calculate, the inputs and outputs; hence we can model how the soil water content is changing from day to day. Fig.2.3 shows the maintaining of water level in an irrigation scheduling.

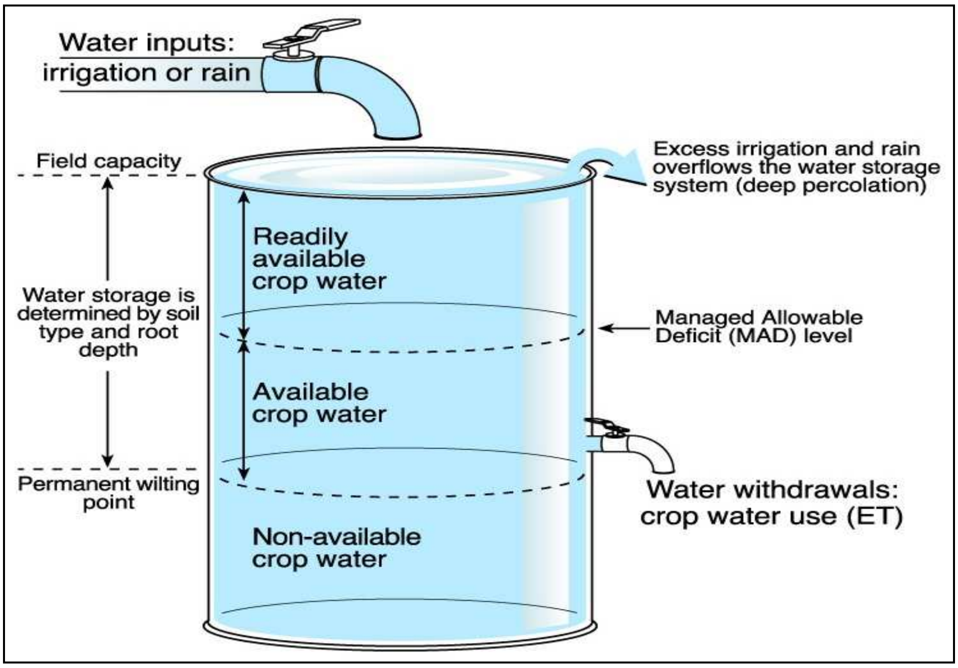


Fig.2.3. Maintaining water level in Irrigation scheduling, Source: http://av.vet.ksu.edu/

Snyder *et al*. (2000) developed the "Basic Irrigation Scheduling" (BIS) in MS Excel to be helpful for planning in irrigation management of different crops. BIS calculates annual trends of ETo applying daily mean climate data by month, and it contains the most up-to-date crop coefficient information available in California. The BIS application helps with the estimation of daily crop coefficient (Kc) values and crop Evapotranspiration (ETc), it assists to discover yield doorways and management allowable depletions, and it provides a check book approach for determining irrigation timing and amount.
Georgea *et al*. (2000) developed an "irrigation scheduling model" (ISM) which is composed of a "database management system" (DBMS).The model has two elements, soil water and balance crop yield. This "Irrigation Scheduling Model" (ISM) is developed based on mass

conservation approach and "graphical user interface" (GUI) which has the ability for performing irrigation scheduling under divers management and the option for both single and multiple fields. The data which is needed are climatologically, crops and soil information. In addition the model offers a choice of one or more method for calculating reference Evapotranspiration (ETo). The model was tested against field data and CROPWAT model.

Forouda *et al.* (1992) developed a microcomputer –based simulation model for on farm irrigation. The model simulation was based on daily water balance approach of the crop root zone. The model assumes to address the simulation of crop water in root region, irrigation requirement and soil water. The crop water to be used is estimated from potential Evapotranspiration and the crop coefficient which is suitable for the specific crop and time period.

To support farmers in improving the management of on-farm irrigation water; the technical irrigation scheduling activities would be most appropriate tool. The efficiency of irrigation scheduling program should be based on the precise computation of (Crop Evapotranspiration ET) and crop water demand (Aaron, 2005).

2.5 Optimal Cropping Pattern

To investigate optimal cropping pattern and water allocation, whenever water availability is not sufficient to meet the crop water requirement the following factors have to be taken in to account

- To emphasis on intensive irrigation to meet crop water requirement and gain maximum net benefit.
- Reduce the cultivated area to make better adjustment based on supply and demand.
- To consent the cultivation area with a certain reduction in yield, emphasis for extensive irrigation to meet partial crop water requirement.

It is absolutely essential to consider more area under cultivation or to increase production per unit area of available land and water resources because, to satisfy the high demand for food to an increasing population. On the other hand it's crucial to optimize the available land and water resource to get maximum returns, truly it's difficult to bring additional area under cultivation due to urbanization; moreover the allocation of water for irrigation will probably decrease because of other users like industrials and domestic water usage.

Primarily the selecting of crop patterns depend on different crops having different market prices, crop productivities, investment costs, and water demands. Investment costs include the costs of seed, labor, machines, fuel and fertilizer. Crop water demand is very difficult to analyze because it depends on soil conditions, weather conditions and the growth stage of each crop, besides changes in market demands and price structures.

The second difficulty is referred with constrains imposed by restricted water resources, and particularly in the dry season, when water level in reservoirs are drawn losing and the amount of rainfall is relatively low. The third difficulty is that the budgets of most farmers are very limited.

Linear programming models can be used as an effective tool to optimize cropping pattern in the command areas. The constraints imposed on the objective function of the model should incorporate components that account for farmers' preference on the area to keep under cultivation of different crops (Singh *et al*., 2001).

2.6 Production Cost, Gross Income and Net income

All input requirements cost; farmers have access to the inputs they need for production to meet future demand called production cast. Production cost is covering cost of fertilizer, labor force, irrigation, and other operation which is required for the field.
Gross income is the income before deductions of production costs; the outcome of yield multiplied by market price is presenting gross income. But the Net income is expressing the entire amount of income that a firm has gain after subtracting production costs and expenses from the total revenue.

Net income = ∑ (Gross income – Production C) …………………………..……….… (Eq.5)
Gross income = Market price * yield
Production cost = Fertilizer + Labor + Machine + Irrigation + other production cost

2.7 Review of CROPWAT Model

This study finds out the possible solutions for various problems in conditions of improving irrigation water allocation and use in shortage supply context, to be more specific a case study in Jui-Naw area in Herat province of Afghanistan has been taken out. Hereby, to come up with an appropriate and standard calculation for improving irrigation practices through understanding of crop water requirement, planning of cropping options under various irrigation management system, and other assigned relevant objectives and scopes, CROPWAT model, which is a practical tool for helping researcher to analysis results with draw conclusion, is appropriate to apply in context of this study. Further, use of this model is helping to achieve meaningful comparisons results. And another important property of the CROPWAT model is that, it let to have extension of the decisions and conclusions from studies to conditions not tested in the field. Therefore, it can offer practical recommendations to farmers and extension staff on deficit irrigation scheduling under various conditions of water supply, soil, and crop management conditions.

CROPWAT is a decision support system, originated by "Land and Water Development Division" of FAO by Smith (1992). In order to estimate "reference evapotranspiration", "crop water requirement" (CWR) and to support "Irrigation water requirement" (IWR). The algorithm for the estimation CWR and IWR in the model is based on the calculation of the reference evapotranspiration (ETo) which is counting as per Penman-Monteith and other crops parameters. To develop irrigation scheduling under different management system and scheme supply, to evaluate irrigation application efficiency, rain fed production and effect of drought, CROPWAT would be the appropriate tool for developing these all. Climatic and crop data are essential as inputs for CROPWAT. In addition, the CLIMWAT- database is obtained for 144 countries for climate data. The development of irrigation scheduling, rain fed agriculture evaluation and over all irrigation practices are grounded on a daily soil water balance approach using various alternatives in terms of supply and irrigation management system. (Amir, 2001)

2.8 Review of Win-QSB Model

The Quantitative System for Business (QSB) is a capable decision support system which offers range of right tools that is widely used problem–solving algorithms in Operations Research and Management Science (OR/MS). WinQSB is the windows version of QSB software package that runs under the CD-RAM windows. This software was developed by Yih-ong Chang. Professor Hossein Arsham (1994).

Almost all the software package uses the simplex algorithm, which is based on Algebraic method. The inputs for solving LP/ILP are given in the following:

- The objective function criterion (Max or Min).
- The type of each constraint.
- The actual coefficients for the problem.
- The typical outputs obtained from LP software are:
- The optimal values of the objective function.
- The optimal values of decision variables. That is, optimal solution.
- Reduced cost for objective function value.
- Range of optimality for objective function coefficients. Each cost coefficient parameter can change within this range without affecting the current optimal solution.
- The amount of slack or surplus on each constraint depending on whether the constraint is a resource or a production constraint.
- Shadow (or dual) prices for the RHS constraints. We must be careful when applying these numbers. They are only good for "small" changes in the amounts of resources (i.e., within the RHS sensitivity ranges).
- Ranges of feasibility for right-hand side values. Each RHS coefficient parameter can change within this range without affecting the shadow price for that RHS.

For this study linear programming and Integer linear programming has been used to address the maximization of NB, calories Production and minimization of fertilizer and labors to arise with an appropriate solution for optimizing cropping options.

CHEPTER 3

METHODOLOGY

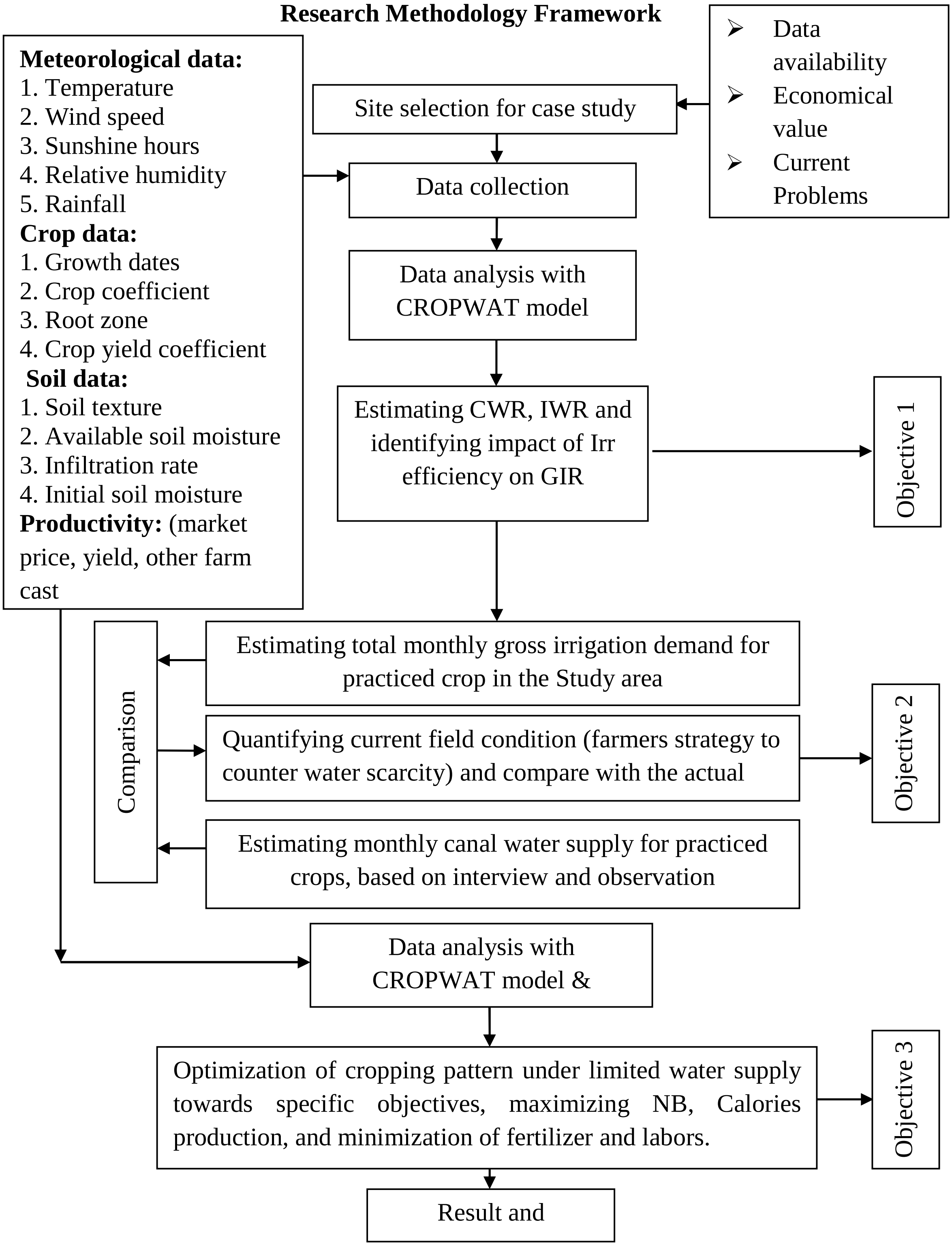
3.1 Research Methodology Framework

In general the concepts of this study comprehend a case Study in Jui-Naw irrigation system in Herat Afghanistan, which is devoted for improving the irrigation water allocation and use for different crops. For this reason the solution ways for relevant problems have been addressed, through the assigned scopes which are the application of CROPWAT model to first estimate crop water requirement (CWR), irrigation water requirement (IWR) and identifying impact of irrigation efficiency on GIR. Secondly, monthly irrigation water demand for practiced crops is estimated in the case study area with the model help thereafter, based on the structured questionnaire and field observation canal water supply is estimated for understanding current field situation on the account of water demand and supply. Thirdly, for investigating possible cropping system on account of optimal and sub-optimal water supply different management scenarios have been tested, as follows;

- Reducing area of all crops towards optimal supply of water, and IWR satisfaction,
- Eliminating some crops towards optimal supply of water, and IWR satisfaction,
- The model also has been used to keep all crops but with sub-optimal supply of water

The scenario results have been evaluated from economic and calories production point of view. Quantitative System for Business (Win-QSB), which is an optimization tool that use simplex algorithm, has been used to identify the cropping system option, through the maximization of net economic return (NER), calories production, and minimization of fertilizer and crop labor requirement. Consequently, the suggested methodology conceptual framework for this study is figured out in the next page.

Research Methodology Framework



3.2 Methodology For Over All Objectives

3.2.1 Estimation methodology for CWR and IWR

To find out the crop water requirements (CWR) and irrigation water requirements (IWR) through CROPWAT model the following steps and information is required.

- Decade or monthly climate data that is minimum and maximum air temperature, relative humidity, sunshine duration and wind speed is required by the model.
- Reference crop evapotranspiration (ETo) equation based on Penman-Monteith method

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad \text{……………………………………………… (Eq. 6)}$$

Whereas,

ET	= reference evapotranspiration [mm day-1]
Rn	= net radiation at the crop surface [MJ m-2 day-1]
G	= soil heat flux density [MJ m-2 day-1],
T	= mean daily air temperature at 2 m height [°C]
u2	= wind speed at 2 m height [m s-1]
es	= saturation vapour pressure [kPa]
ea	= actual vapour pressure [kPa]
es-ea	= saturation vapour pressure deficit [kPa]
Δ	= slope vapour pressure curve [kPa °C-1]
γ	= psychrometric constant [kPa °C-1]

- Rainfall data (daily/decade/monthly) is required to calculate effective rainfall, for this study USDA Soil Conservation Service method has been chosen for the calculating of effective rainfall; following criteria have to be followed.

ER = Total R*(125-0.2 TR) / 125 …… ………………………….……………….. (Eq.7)
(For Total Rainfall < 250mm)
ER = 125 +0.1 * Total Rainfall …………………………….…….……...….. (Eq.8)
(For Total Rainfall > 250mm)

- A cropping pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area) and also a set of typical crop coefficient data files are provided in the program.

CWR and IWR computes due to the following formula, on the account of CROPWAT model.

CWR = ETo* Kc ...……………..………………….………….................................. (Eq. 9)
IWR = (ETo* Kc) – ER.… ……………………………….……………………..... (Eq.10)

3.2.2 Estimation methodology for irrigation scheduling

To estimate Irrigation Scheduling these options should be taken in to account

- Defined times, date, and depth by users
- Application timing
- Irrigate when a specified % of Readily Soil Moisture Depletion occurs.
- Irrigate when a specified % of Total Soil Moisture Depletion occurs.
- Irrigate when a specified % of Soil Moisture Depletion occurs.
- Irrigate at Fixed Intervals (day).
- Irrigate at Variable Intervals (User- Defined) (days)
- Application Depths
- Refill to a specified % of Readily Available Soil Moisture.
- Fixed Depths (mm).
- Variable Depths (user- Defined) (mm).

Model requires information on, Soil type, total available soil moisture, maximum rooting depth and initial soil moisture depletion (% of total available moisture). The best scenario will be select based on existing cropping pattern and site adaptability. Hence, after fixing scheduling have to find out the actual crop water requirement and irrigation water requirement.

3.2.3 Estimation methodology for comparison of current and actual field condition

For understating the current and actual field situation it's required to know how much water is given for difference crops in each month for the practiced crops in the study area, with the existing irrigations efficiency, secondly it's necessary to explore monthly canal available water for the crops in the study area. CROPWAT is taken in account for simulating the net irrigation requirement of each crop in the study area, and canal flow is estimated based on the rectangular weir formula. The result of this scenario helps to quantify that which crops are suffering from water shortage, which is an important factor for yield reduction, and which crops are not facing water scarcity and what are farmers measure in case of water shortage.

3.2.4 Estimation methodology for optimization of cropping pattern

The result from the previous objectives helps to understand the real field condition, and it would be better guild for appropriate decision for optimizing cropping patterns. Different scenarios are tested for understanding the optimal situation, reducing area of all crops and optimal supply of water, eliminating some crops and optimal supply of water, and last the model also has been used to schedule the sub-optimal supply for all practiced crops. The WinQSB, which is an optimization technique tool, has been taken in account to help for identifying cropping system options, with respect to the maximization of net economic return (NER), calories production, and minimization of fertilizer and labor under limited water supply.

The scenario results have been evaluated from economic and calories production point of view. The information which is needed to address the economic assessment are, yield, market price, and production cost. The component which are involve in production cost are, fertilizer, labor, irrigation cost and finally field operation cost if exist. Understanding calories contents of practiced crops is required for maximizing calories production due to available water and land.

3.2.5 CROPWAT model output

Once all the data is entered, CROPWAT 4 Windows automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. The output parameters for each crop in the cropping pattern are

- Reference crop Evapotranspiration – ETo (mm/period)
- Crop Kc - average values of crop coefficient for each time step
- Effective rain (mm/period) - the amount of water that enters the soil
- Crop water requirements – CWR or Etm (mm/period)
- Irrigation requirements –IWR (mm/period)
- Total available moisture –TAM (mm)
- Readily available moisture – RAM (mm)
- Actual crop Evapotranspiration – ETc (mm)
- Ratio of actual crop Evapotranspiration to the maximum crop evapotranspiration ETc/ETm (%).
- Daily soil moisture deficit (mm)
- Irrigation interval (days) & irrigation depth applied (mm)
- Lost irrigation (mm)– irrigation water that is not stored in the soil (i.e. either surface Runoff or percolation)
- Estimated yields reduction due to crop stress when (Etc/Etm) falls below hundred percent. Following Eq.8 represents crops yield reduction in CROPWAT mode in each stage of crops life.

$$\left(1-\frac{Ya}{Ymax}\right)=Ky\left(1-\frac{ETc}{ETmax}\right) \quad \text{(Eq.11)}$$

Ya = crop actual yield and
Ymax = maximum crop yield
Ky = crop yield reduction factor
Etc = evapotranspiration, respectively
ETmax = potential evapotranspiration

The CROPWAT model after finishing the irrigation scheduling process, it can set up to estimate the monthly agriculture water requirement on the irrigation scheme, based on the various cropping patterns as showed in the equation as below.

$$Q_{gross} = \pi r^2 = \frac{1}{e_{p \times t}} \times (0.116 \times Aschem \times \sum_{i=1}^{n}(ETc - ER) \times Ac/As) \ldots\ldots\ldots\ldots\ldots \text{(Eq.12)}$$

Q_{gross} = monthly agricultural water requirement of irrigation scheme (l/s)
e_p = irrigation efficiency (<=1, dimensionless)
t = time operational factor (<=1, dimensionless)
I = crop index of the cropping pattern for an irrigation scheme
Ac = crop planted area (ha)
As = total area of irrigation scheme (ha)
Etc = crop evapotranspiration (mm/day)
ER = effective rainfall (mm/day)

3.3 Introduction of Some Parameters Related To the Model

3.3.1 Reference crop evapotranspiration (ETo)

Base on Amir (2001) the processes which makes up the coincident motion of water from the soil and vegetation surfaces into atmosphere through evaporation (E) and transpiration (T) can be called evapotranspiration (ET). Reference crop evapotranspiration ETo defined as the rate of evapotranspiration to present the atmospherics evaporative need from a supposed reference crop to have an accepted crop height (12 cm), with the specific features of grass, fully covering the soil and actively growing with adequate water, and with a fixed crop surface resistance (70 s m-1) and albedo (0.23)., crop type and its management practices factors does not have any effect on (ETo).This shows that ETo is merely a climatic parameter and can be estimate from weather data.

It will be very easy and useful to chose a logical (Kc) as per our understanding of reference crop evapotranspiration and to calibrate evapotranspiration equation according a local data. In order to exchange (Kc) from one site to another the realizing of reference Evapotranspiration is in a crucial sense. The reference evapotranspiration, ETo, allows for a standard to which, evapotranspiration at different periods of the year or in other regions can be compared and moreover, evapotranspiration of other crops can be related.

Based on FAO, Irrigation and Drainage paper No.24 evapotranspiration can be estimate by four methods due to climatic data accessibility which are

- Blaney- Criddle Method
- Radiation Method
- Penman-Monteith Method and
- Pan Evaporation Method.

Suat (2003) International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organization of the United Nations (UNFAO) expert consultation highly recommend the Penman-Monteith method for estimation of evapotranspiration than other methods, because this method is used as the standard method and encompasses both physical and aerodynamic parameters. In addition with this method a process has developed to calculate the missing climatic data. Moreover Penman glide path in both arid and humid region has been showed very accurate and logical in both ASCE and European research studies.

3.3.2 Crop coefficient (Kc)

Crop coefficient (Kc) which is a crucial factor in sense of calculating crop water requirement, shows the difference in evapotranspiration among cropped and a reference grass surface. (Kc) values are quite dissimilar due to crops and the stage of crop development growth. For a crop development stage we have four stage, initial, crop developments, mid season and, late season,

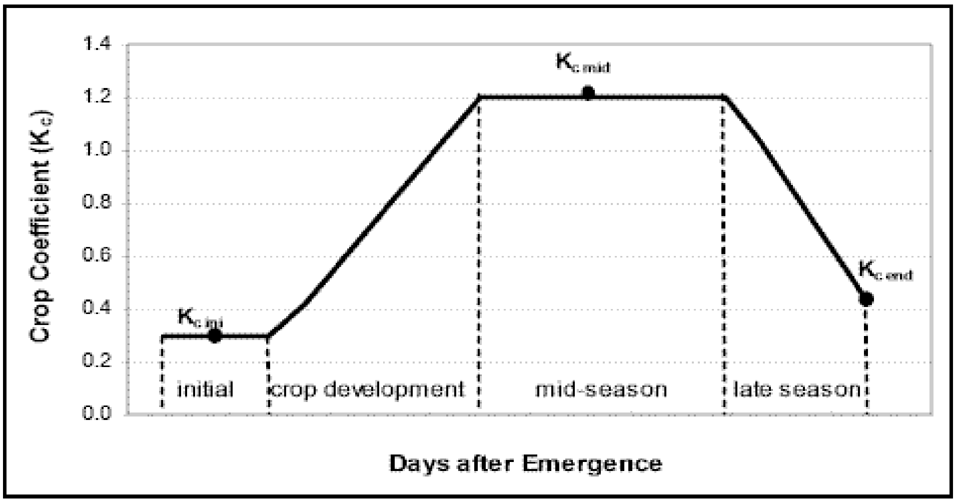


Fig: 3.1. Crop coefficient curve, Source: **http://www.dpi.qld.gov.au**

Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc) are used to relate ETc to ETo or (ETc=KcETo) The crop coefficient values can be calculated by CROPWAT model based on climatic and crop type information.

3.3.3 Effective rainfall

The part of the total precipitation which can satisfies Evapotranspiration requirement of crops can be called effective rainfall. The part of rainfall that cannot take part in crop water requirement satisfaction will lost through soil drainage or by runoff over the soil surface.

Four methods for estimating effective rainfall derived from experiment and observation (Smith 1991) firstly fixed percentage of rainfall, secondly dependable rainfall thirdly empirical formula, and lastly USDA Soil Conservation Service Method.

- **Fixed percentage of rainfall**: In this method a typical range between 0.7 up to 0.9 will consider by model user as a specific coefficient,
  ER = a * R……..…………………………………………………………...….. (Eq.13)
  a = specific coefficient
  ER = Effective rainfall
  R = Total rainfall

- **Dependable rainfall:** This method which is developed by FAO can be used more for designing purpose to estimate dependable rainfall.
  ER= 0.6TR – 10…………….…………………………………………………..… (Eq.14)
  This equation is valid where (TR < 70mm)
  ER= 0.8TR – 24………………………………………………………………… (Eq.15)
  Equation 12, is valid when (TR>70 mm)
  ER = Effective Rainfall
  TR = Total Rainfall

- **Empirical formula:** This method grounded on analyzing the formula which is dependent on local climatic data to determine the effective rainfall.
  ER = a (Total Rain) + b……..……………………………..…...………………. (Eq.16)
  For TR < z mm
  ER = c (Total Rain) + d……..…………………………………......………… (Eq.17)
  For TR > z mm
  Where a, b, c, d and z are empirically derived correction coefficients

- **USDA Soil Conservation Service method:** In this case we have the bellow criteria
  ER = Total Rain = ……..…………………...…………………..….............. (Eq.18)
  For Total Rainfall < 250mm
  ER= 125 +0.1 * Total Rainfall……..……………………………………..... (Eq.19)
  For Total Rainfall > 250mm)

3.3.4 Total available moisture and readily available moisture

The field capacity minus permanent wilting point multiplying to crop rooting depth can be called (TAM).On the other hands, to avoid crops from water stress soil moisture should be kept above the Readily available moisture which can be define as the result of multiplication of TAM to depletion friction factor that is P, (FAO, 1998).
RAM = TAM* P ……. ………………………………………………………………. (Eq.20)

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.1 Study Area Description

The present case study area is located within the Jui-Naw irrigation system of Afghanistan. It is situated to the western part of the country in the lower Hari Rod river basin. Location map of the study area within the Jui-Naw irrigation system is presented in Figure 4.1.

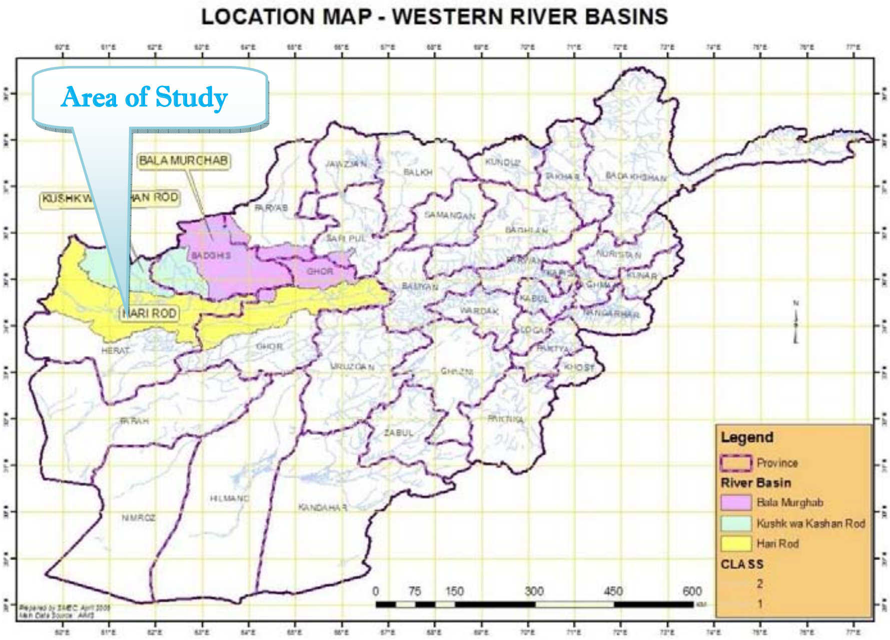


Fig.4.1 Map Showing the Hari-Rod River Basin

The study area is selected based on three point of view, first of all based on the current problem which exists, according to the study which has been done through the Asian Development Bank (ADB, 2005), solution ways for the problems addressed as bellow,

- improved water availability,
- better efficiency of distribution, and
- Increased productivity and returns from water.

Secondly, the economic point of view of the area has been considered. Jui-Naw is the largest irrigation system covering a total area of 7645 hectares. There are 7,000 households living in the command area of Jui-Naw irrigation system. In addition, from a total available irrigable area of 5,133 hectares in system, only 50% of the cultivable area can be irrigated (ADB, 2005). Table 4.1 presents the summary of command and irrigable areas for the three sections

Table.4.1. Command and Irrigable Area in Jui-Naw Irrigation System (ADB, 2008)

Section	**Area (ha)**	
	Command	**Irrigable**
Upper	2637	1928
Middle	2601	1901
Lower	2407	1304
Total	7645	5133

And last criteria for justifying the selected area for this study was data availability, overall data availability is a big constraint for researcher in Afghanistan but, so far some studies have been done on this area making it possible to get some data.

Herewith, the objectives which are defined for this study seem to match the problem that ADB has identified for this area, hence this area is accepted in terms of problem, economical value and data availability. Fig.4.2 shows an illustration of Jui-Naw irrigation system.

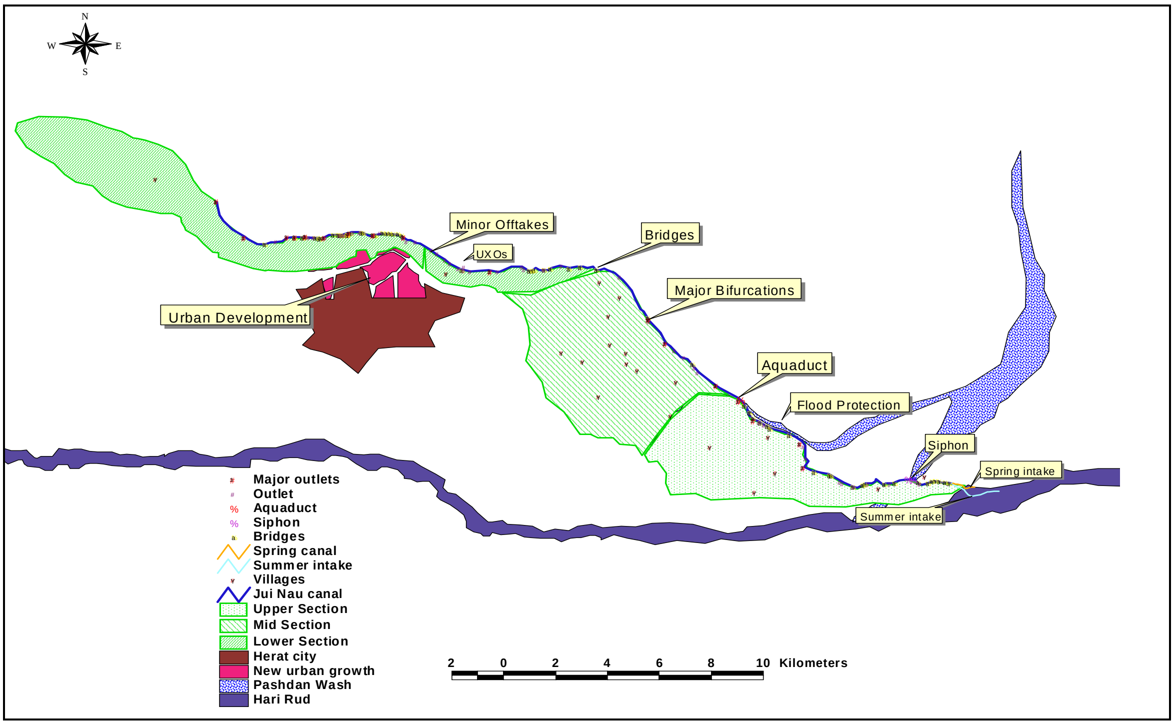


Fig.4.2.Jui- Naw irrigation system map. (ADB,2005)

4.1.1 Water Allocation in Jui-Naw Irrigation System

In general every canal in Hari-Rod river basin is given a specific water right. The water right is allocated based on the village area. The canals are feeding up with two different intakes; these intakes are building upon the availability of water in the Hari-Rod River. The main intake is called spring intake when the amount of water is higher, and the summer intake usually used when water is less in the river compare to spring season. There are natural springs in the river bad, when flow is blocked for feeding one canal in one intake the flow of water is stopped in that intake completely specially during summer season, but natural springs generating enough of water to feed the next canal in downstream.

Water right in jui-Naw canal is given based on the size of holding in different location (upper, mid, and lower section), different right is given. The water is allocated by two main kinds of structures, locally called Qulb and Natra from the main canal to other branches. The lands which are located lower than canal bed getting water from Qulb structure. Qulb is basically circular shape close structure, which feeds from main canal and opens in the sub-branch. The water right in upstream, mid stream and downstream is various from each other, for example, the diameter of Qulb in upstream for one Zawj (80 Jarib) is 1.75 inches, in mid stream for one Zawj (100 Jarib) is 1.63 inches, while in downstream for one Zawj (120 Jarib) is equal to 1.5 inches.

The second structure, which is used for water allocation of water right, is locally called Natra. Natra is an open square shape structure usually used for the allocation of water right for the lands located in a similar elevation to canal bad. Allocation of water from this type of structure requires building a main Natra (weir) in the main canal stream to block water in a specific position. The water level rise up in that point from where further Natras are build for allocation of water to specific lands. The dimension of a sub Natra, which is built for allocation of water for a specific land area is equal to the total length of main Natra in the canal divided by the area of that specific land (Zoaj), holding size.

Table.4.2. Water Allocation In Jui-Naw

Section	Jerib/Zawj	Zawj/section
Upper	80	85.75
Middle	100	70.25
Lower	120	145.75
Total		301.75

1- One Jerib is equal to 2000 m^2

Maximum intake flow in Jui-Naw by simple flow measurement and canal capacity verified 8cum/sec in spring intake. Of course when the intake is shifted to the summer intake the peak flow drops to less than 4cum/sec.

4.1.2 Uordo-Khan Canal

A branch of Jui-Naw canal, which is representing the whole scheme, has been considered for fielded farmer interview and data collection. The name of this branch is Uordo-khan canal. The total area which is covered by this canal is 400 ha, after 6km from the intake this canal is divided into two branches, the coverage of each branch is 200 ha, one of this branch passing through Uordo-khan Research farm and the other one flowing through Uordo-khan village and its divided into three branches, which are Poshta-Dae, Qale-Komaidan, and Zire-Dae. The irrigation coverage of each branch respectively is 80 ha, 40 ha, and 80 ha. Figure 4-3 is illustrating a sketch of this scheme.

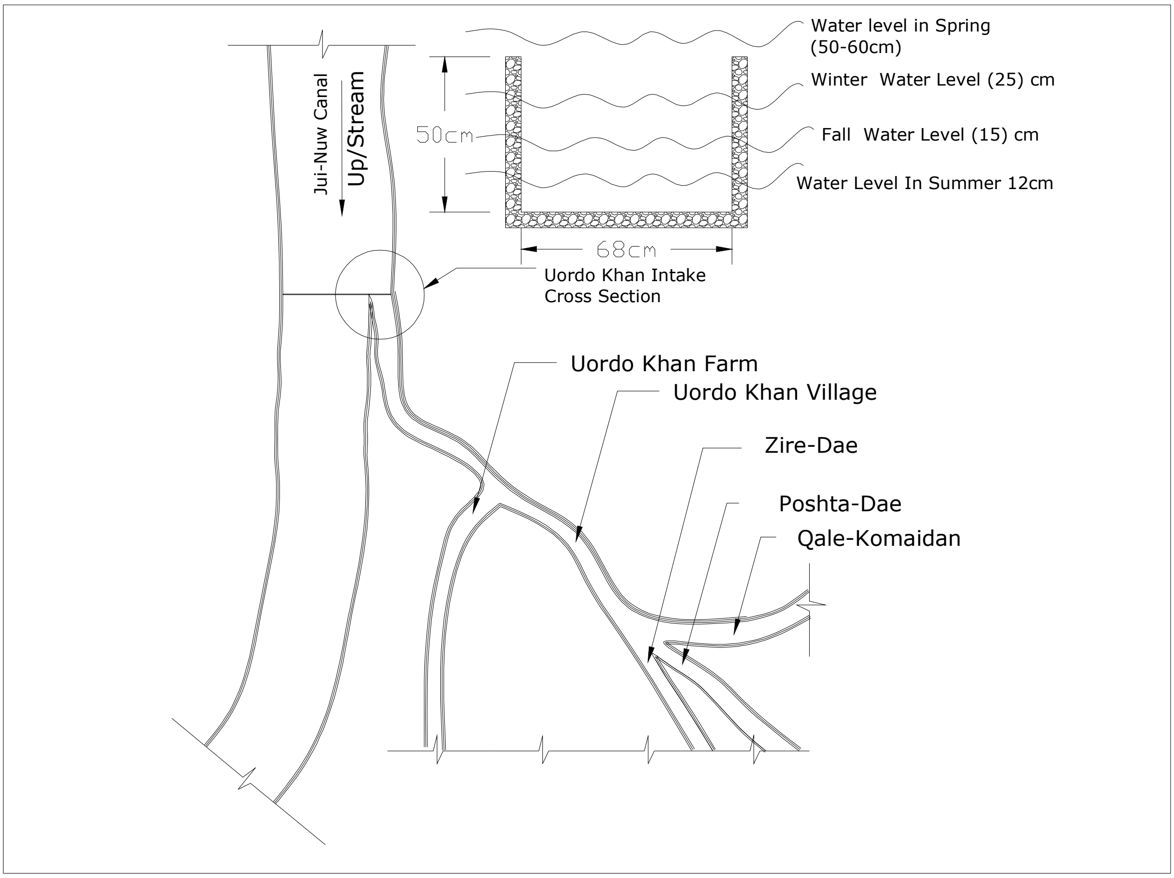


Fig.4.3. Uordo-Khan canal description map

4.1.3 Uordo-Khan Canal Flow Calculation

For calculation of flow in Uordo-Khan canal which is considered as a rectangular weir the Francis's formula has been used as following.

$$Q = \frac{2}{3} C_d \sqrt{2g} (L - 0.1nH) H^{\frac{3}{2}} \quad \text{.........} (Eq.21)$$

Q = Discharge of water flowing over a rectangular weir (m3/sec).
C_d= Discharge coefficient
L= clear length of weir (m)
H= Water head on the crest (m)
n= is the number of end contraction.

The value of C_d for a rectangular weir is 0.623 according Francis's formula. The n value due to formula condition is 4 with respect the field situation.

H_{spring} = 55cm, L= 68cm, n= 4, and C_d=0.623
Q_{spring} = 345.24 liters/S
H_{summer} = 12cm, L=68cm, n=4 and C_d=0.623
Q_{summer} = 48.34 liters/S
H_{fall} = 15cm, L=68cm, n=4 and C_d=0.623
Q_{fall} = 66.27 liters/S
H_{winter} = 25cm, L= 68cm, n= 4, and C_d=0.623
Q_{winter} = 133.4 liters/S

A maximum flow rate is occurring in the Uordo-khan canal during the spring period and the minimum one is occurring during summer period.

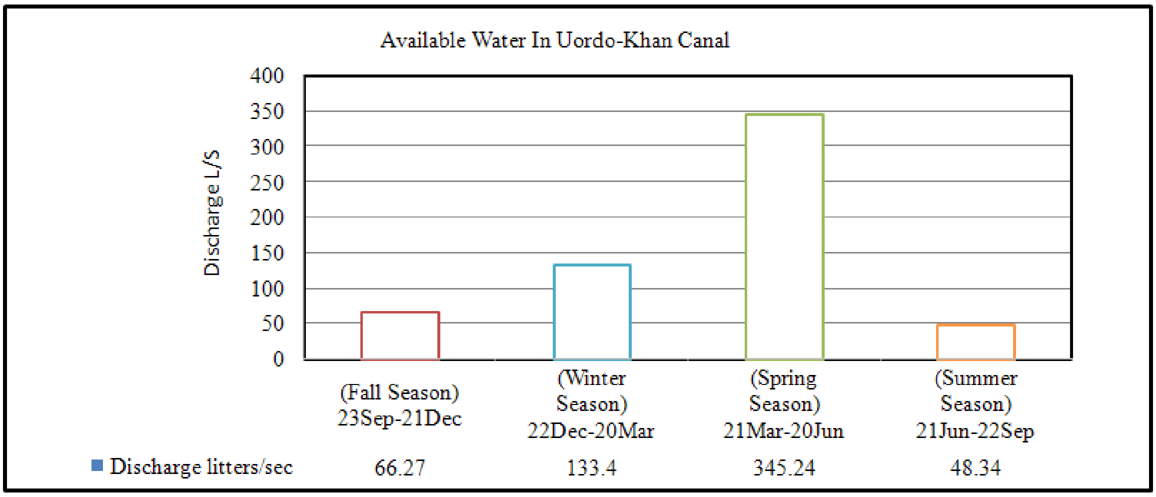


Fig.4.4: Available Water In Uordo- Khan Canal During Different Season

4.2 Fieldwork

Fieldwork has been covered almost all the necessary hydro-Metrological data, which are necessary as input for CROPWAT model, as well as farmer interview throughout structured questionnaire and formal interviews with various groups about agriculture water use, water allocation, irrigation methods and crop calendar.

Reconnaissance survey has been carried out for identifying the site and gaining information about the current situation in the field. All over, 50 farmers was conducted to a formal interview for collecting primary farm information, cultivated area, water allocation system, crop type and rotation, irrigation scheduling, irrigation practice and furthermore, farmers were called for sharing their knowledge on alternative cropping pattern and water supply sources.
The secondary data was collected from various governmental and non-governmental both national and international organization involved in related studies. Of course, some information like soil, crop coefficient, crop rooting depth and crop yield response factor has been gathered through review of various reliable publications.

Table 4.3. Description of collected data

Location: HEART-AFGHANISTAN		Latitude: 34^0 18.819/	Longitude: 62^o 19.033 /		Altitude: 965m	
DATA	**Duration**		**Frequency**		**Source**	
Meteorological data.	Old Data	New Data	Old Data	New Data	Old Data	New Data
Temperature	1942-1988	2000-2007	Mean Monthly	Mean Monthly	HERAT Irrigation Department	Uordo- Khan Research Farm
Precipitation	1942-1988	2001-2008	Mean Monthly	Mean Monthly	HERAT Irrigation Department	Uordo- Khan Research Farm
Relative Humidity	1942-1976	2001-2007	Mean Monthly	Daily	HERAT Irrigation Department	Uordo- Khan Research Farm
wind speed		2002-2008		Mean Monthly		Uordo- Khan Research Farm
duration of sunshine		2001-2008		Daily		Uordo- Khan Research Farm
Soil Data						
Soil available moisture					Fundamental Irrigation paper	
Soil Texture					Uordo- Khan Research Farm	
Soil infiltration rates					Fundamental Irrigation paper	
Crop data						
coefficient (Kc)					FAO-Paper # 56	
Crop yeild response factor (Ky)					FAO-Paper # 56	
Crop Calendr					Structured questionnairy	
Crop Rooting Depth					FAO-Paper # 56	
Croped Area Clasification					Structured questionnairy	
Irrigation Information						
Irrigation scheduling					Structured questionnairy	
Irrigation interval					Structured questionnairy	
Production cost					Structured questionnairy	
Yield Reduction					Structured questionnairy	
Productivity					Structured questionnairy	

4.3 Metrological Data Analysis

The required climatic data from 1942 to 1988 has been collected from Irrigation department. The climatic data from 1988 to 2000 is not available, because of interior country conflicts. The recent climatic information from 2001 to 2008 has been collected from Urdo-khan Research Farm.

4.3.1 Rainfall Data

In context of this study mean monthly rainfall data serve the purpose, the following figure shows the trend, by using the average monthly values over a period of past fifty four years, additionally the mean monthly rainfall of recent eight years is also shown. For the purpose of this study long term mean monthly rainfall is valid and it shows more accuracy than short term.

Figure 4.5 represents a typical arid pattern. The hottest months are from May to Sep whereas, the maximum mean monthly rainfall received from (1942-2008) is 54.29mm in March and based on short period from 2001 to 2008 the maximum mean rainfall received is 41.92mm in January.

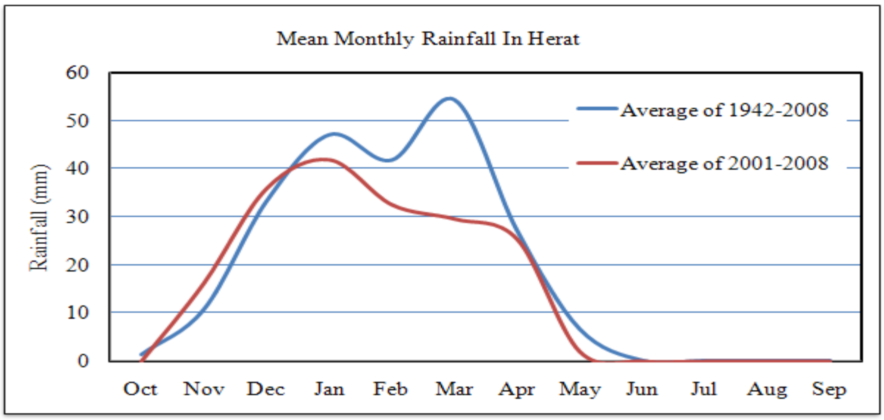


Fig.4.5. Mean monthly rainfall of the Study Area

4.3.2 Temperature

Mean maximum and minimum temperature data is required for CROPWAT model, as mentioned in table 4.3, all the historical climatic data from 1942-1988 is collected from department of irrigation and the recent temperature data from(2000-2007) has been collected from Uordo-khan Research farm, the long term minimum and maximum mean temperature is used to achieve the objectives of the study.

Table.4.4. Mean, Maximum mean, and Minimum mean Temperature

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Temp (2000 to 2007)	17.56	11.40	5.96	4.75	7.50	11.87	17.88	22.83	27.15	29.16	29.07	23.56
Mean Temp (1942 to 2007)	16.36	9.39	4.88	3.50	5.93	10.71	16.79	22.72	27.70	30.29	28.79	23.43
Mean Min	11.5	3.7	-2.3	-6.7	-4.4	5.8	11.1	18.8	23.5	26.6	24.7	20.3
Mean Max	20.75	15	10.3	6.6	10.9	14.4	21	26.4	30	33	35	29.3

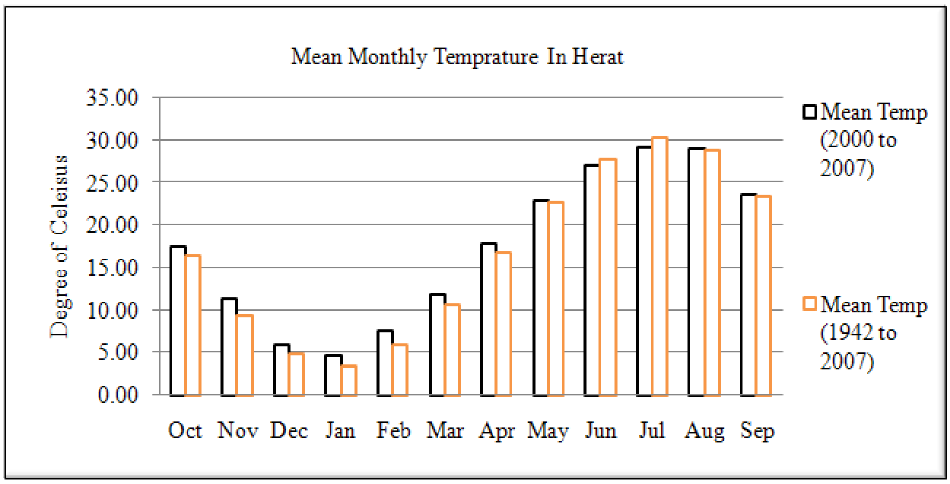


Fig.4.6. Mean monthly temperature from 1942-2007 and from 2001-2008

4.3.3 Wind Speed

The mean monthly wind speed in the study area as well as other metrological information has been collected from Uordo-Khan Research Farm. The following figure shows wind speed trends, it depicts maximum mean wind speed in July and August (17km/hr), and the minimum speed observed in December and January (6km/hr).

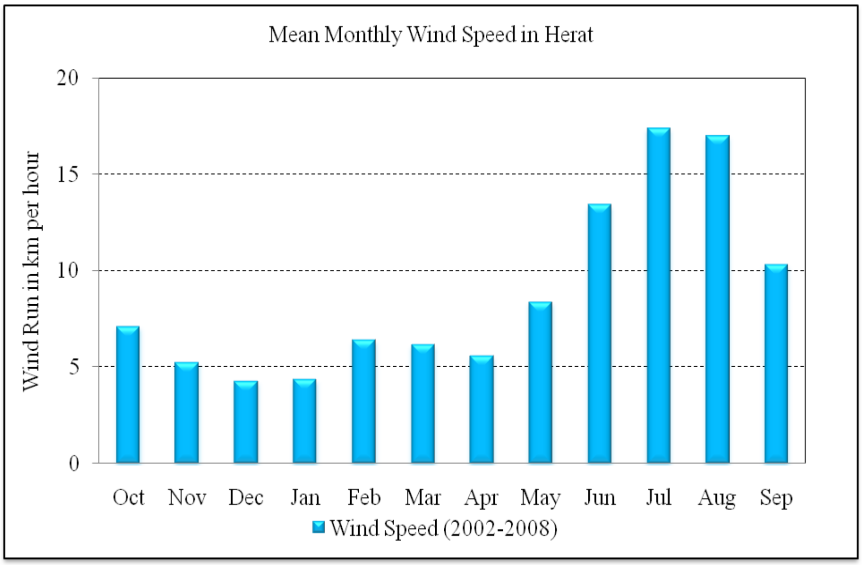


Fig.4.7. Mean monthly Wind speed according to average of 2002-2008

4.3.4 Relative Humidity

Since, relative humidity is another parameter which is required for CROPWAT model, this parameter also obtained from Irrigation Department based on mean monthly from (1942-1976), and the recent humidity data has been collected daily base from Uordo-Khan research farm. The long term data has been considered for developing the COROPWAT model. The graph shows maximum RH in Jan (69.49 %) and minimum in Jul (29.13%).

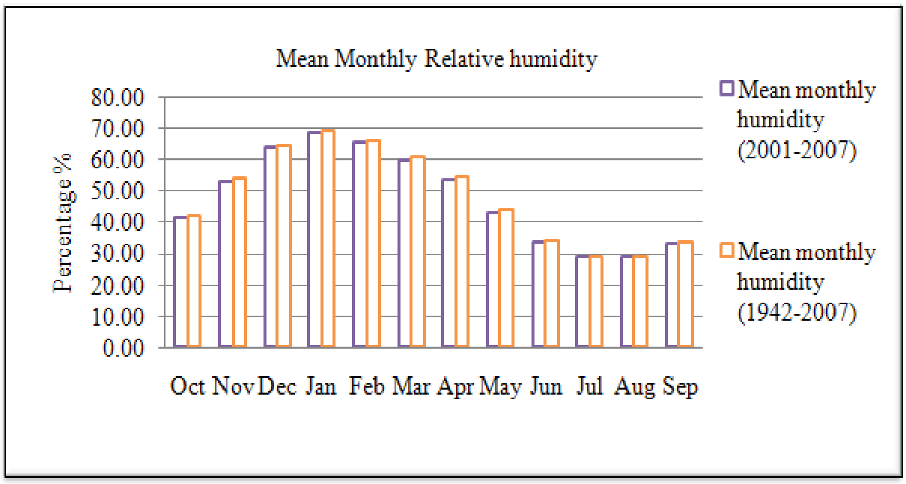


Fig.4.8. Mean Monthly Relative Humidity in the Study Area

4.3.5 Sunshine hours

Sunshine hour is anther climatic input for the CROPWAT model. Maximum sunshine hour is in August (11:35hr) and the minimum duration is in December (4:45hr).

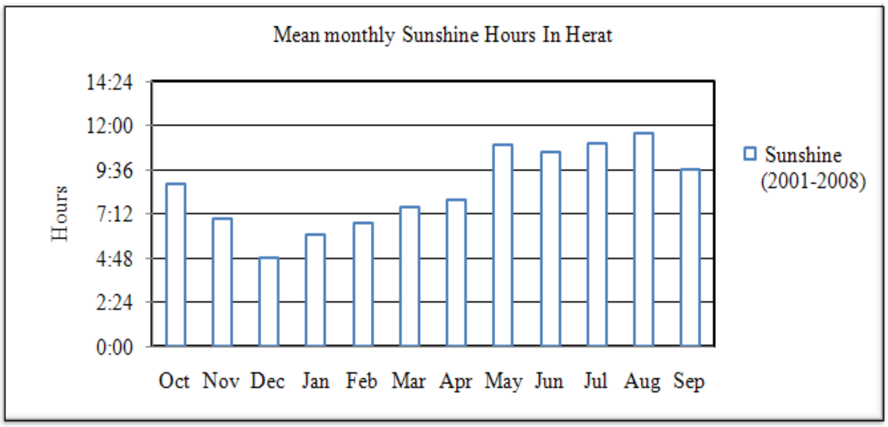


Fig.4.9. Mean Monthly Sunshine Hours in the Study Area

4.4 Soil Data

A soil analytical data and soil map for the study area is scarce. The study area is covered with clay type soil according to Uordo-khan Research farm, and field soil visual observation, the following tables are showing the basic infiltration rate and available water in different soil textures, which are required as soil data in CROPWAT model the maximum available water is defined (150mm/m), and maximum infiltration rate (120mm/day).

Table.4.5.Available Water for different soil texture (Irrigation Fundamental)

Soil Texture	Available Water (AW) (mm/m)
Coarse Sands	20 - 65
Fine Sands	60 - 85
Loamy Sands	65 - 110
Sandy Loams	90 - 130
Fine Sandy Loam	100 - 170
Silt Loams	150 - 230
Silty Clay Loam	130 - 160
Silty Clay	125 - 170
Clay	110 - 150
Peats and Mucks	160 - 240

Table.4.6. Basic Infiltration Rate (Fundamental Irrigation, 2000)

Soil Type	Basic Infiltration Rate (mm/hr)
Clay	1 - 5
Clay loam	5 - 10
Silt loam	10 - 20
Sandy loam	20 - 30
Sand	30 or more

4.5 Crop Data

Crop data which is needed to serve the assigned objectives of this study are depicting in the following tables for the grown crops in the study area.

Table.4.7. Crop Coefficient Kick (FAO, 1998)

Crop	Kc in	Kc mid	Kc end
Wheat	0.55	1.15	0.32
Mungbean	0.4	1.05	0.47
sesame	0.35	1.10	0.25
cotton	0.35	1.17	0.60
Barley	0.30	1.15	0.25
Fodder	0.40	0.90	0.85
Alfalfa	0.40	0.95	0.90
Eggplant	0.37	1.05	0.85
Tomato	0.60	1.15	0.80
Onion	0.70	1.05	0.75

Table.4.8. Rooting Depth, Yield Response factor (Ky) and Depletion Fraction (P) (FAO, 1998; Fundamental Irrigation)

Crop	Rooting Depth (m)	Yield Response factor (Ky)				Depletion Fraction (P)
Wheat	1.5-1.8	0.2	0.6	0.5	0.5	0.55
Mungbean	0.6-1	0.2	1.1	0.75	0.2	0.45
sesame	1-1.5	0.4	0.4	0.4	0.4	0.6
cotton	1-1.7	0,2	0.5	0.4	0.25	0.65
Barley	1-1.5	0.2	0.6	0.5	0.5	0.55
Fodder	0.6-0.9	0.7	0.7	0.7	0.7	0.5
Alfalfa	0.65-1	0.7	0.7	0.7	0.7	0.55
Eggplant	0.7-1.2	0.45	0.45	0.8	0.3	0.45
Tomato	0.7-1.5	0.4	1,1	0.8	0.4	0.4
Onion	0.3-0.5	0.45	0.45	0.8	0.3	0.3

4.6 Crop Calendar

According to the developed cropping calendar in the study area, the stable crop which is occupied almost 50% of irrigable land is wheat merely to fulfill food requirement. The other crops which are practiced in the study area are mungbean, sesame, cotton, barley, fodder, alfalfa, eggplant, tomato, and onion.

CROPING CALENDER IN JUI-NAW IRRIGATION SYSTEM

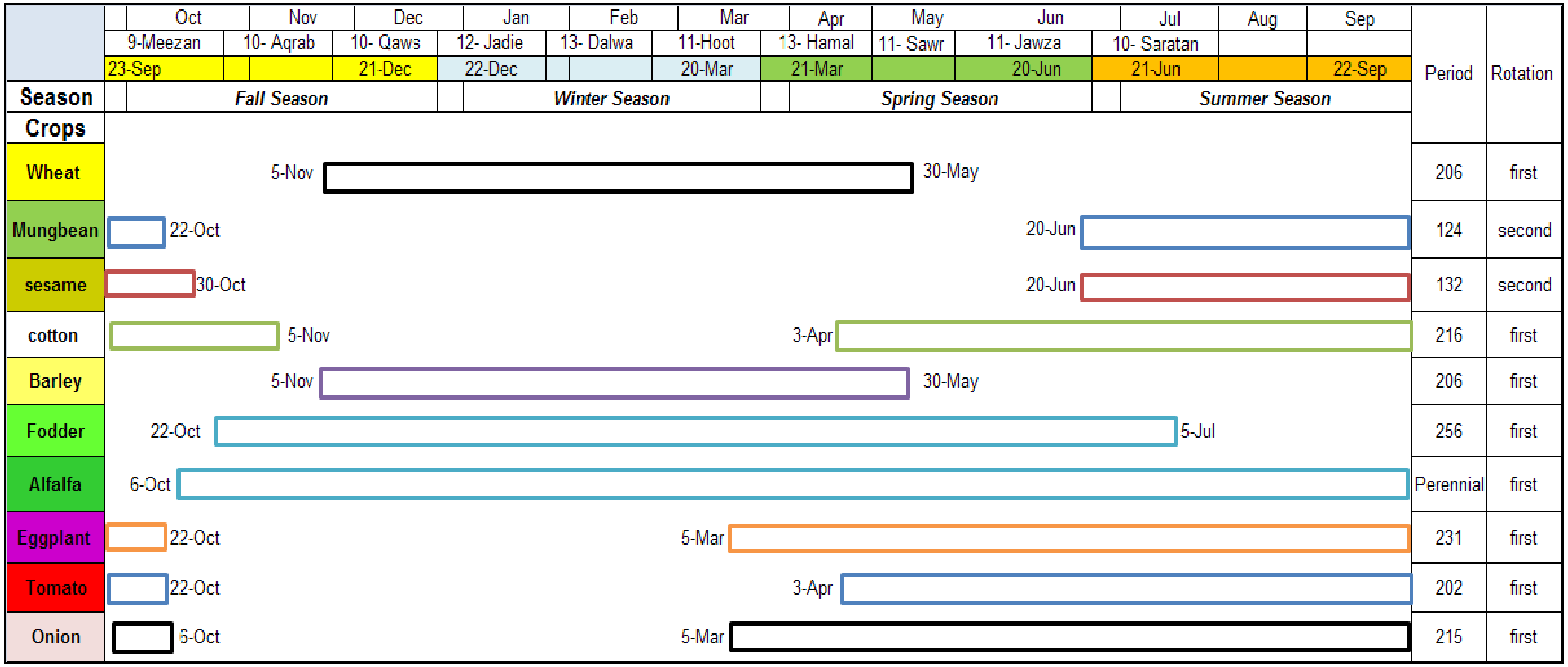


Fig.4.10. Current cropping calendar in the study area – (Jui-Naw Irrigation System- Herat-Afghanistan)

Following figure.4.11 shows percentages of different crops currently cultivated in the study area. The graph reveals that farmers intend to allocate more lands for crops they can cultivated during the winter season, because they think their lands do not need more irrigation water, therefore more land is allocated for crops cultivate in the fall season and harvested in spring season. Due to water shortage in the study area farmers prefer to reduce their cropped land when they feel water is not sufficient to meet the demand therefore, they are not even able to cultivate the available land in the study area. Cropping intensity in the study area is calculated 75 % that means 25% of the available lands are not covering any plants.

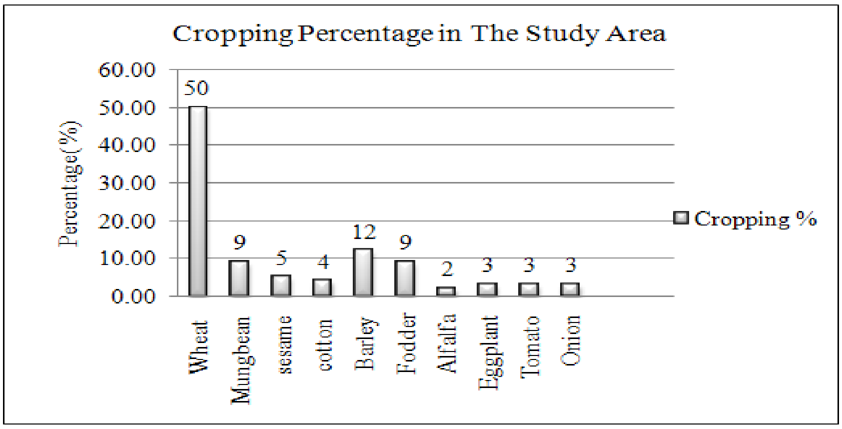


Fig.4.11: Cropping parcentage in the study area

Wheat and barley are covering respectively 50 and 12 percent of the study area, because wheat is the staple food in the area and all farmers prefer to cultivate wheat to supply their households demand. Furthermore, the farmers cultivate these crops with the hope that they will receive precipitation to support their production. These two crops are followed by mungbean and sesame but with reduction of land area because the moisture contents in the soil and availability of irrigation water remains relatively less comparing to the fall and winter seasons therefore, farmers are reducing the cropped land for the second crops. The vegetable crops are also cultivated based on the availability of water. Cropping pattern practiced in the study area is generally based on the traditional knowledge and households needs of the farmers rather than the economic or technical rational.

The analyses have been carried out considering an average situation. But, farmers in the study area have different strategies for dealing with irrigation water availability. Some farmers who can afford the fuel for water pump are using extra groundwater for irrigating. The poor farmers are totally dependent on canal irrigation and precipitation, and their strategies include reduction of the cropping area. Some farmers who keep entire cultivated area practice deficit irrigation. One of the objectives of this study was to investigate the current cropping pattern and available resources and come up with optimal cropping pattern based on maximizing the economic and calorie output in the study area. Different scenarios have been tested to find out the best suitable solution for all farmers in the study area.

4.7 Crops Enterprise Budget Assessment

Content of Table 4.9 demonstrates all components that are used directly for calculation of production cost, gross income and net income.

Table.4.9: Crops economic assessment

Crops Name	Market price Afgs/Kg	Fertilizer		Seed		Labor		Irrigation		Production Cost Afgs	Yield		Net Income Afgs/ha	NET Income USD/ha	SD.of Yield Respons
		Kg/ha	Cost Afghs	Kg/ha	Cost Afgs	person/ha	Cost Afgs	person/ha	Cost Afgs		ton/ha	Gross Income			
Wheat	21	325	8220	125	7000	55	9900	17	3060	28180	3	63000	34820	696.4	0.37
Mungbean	30	65	1209	15	600	10	1800	5	900	4509	0.9	27000	22491	449.82	0.11
sesame	120	100	2295	6	900	15	2700	7	1260	7155	0.8	96000	88845	1776.9	0.11
cotton	80	250	6390	14	700	50	8100	20	2700	17890	3.5	280000	262110	5242.2	0.29
Barley	25	200	4590	110	5500	40	7200	15	2700	19990	2	50000	30010	600.2	0.21
Fodder	4	120	2760	30	6000	60	12000	25	5000	25760	32	128000	102240	2044.8	2.16
Alfalfa	3	150	3660	20	5000	65	13000	30	6000	27660	100	300000	272340	5446.8	10.54
Eggplant	5	220	5490	0.25	4000	40	8000	16	3200	20690	11	55000	34310	686.2	0.77
Tomato	9	250	4590	0.3	4800	45	9000	20	4000	22390	12.5	112500	90110	1802.2	1.05
Onion	8	300	7320	15	4500	75	15000	35	7000	33820	16	128000	94180	1883.6	0.84

Hint: Rate of change for USD to Afghani is (USD 1 = 50 Afgs)

The data in the table shows gross income, net income and production cost. It indicates that the alfalfa and cotton are the crops with higher net income, the market price of alfalfa is low but the yield per hectare is very high whereas, the cotton yield per hectare is not high but the market price is very high. Mungbean, barely, eggplant and wheat were found respectively with the lowest net income than the other crops cultivated in the area. The net income production cost and gross income of different crops are illustrated in the chart given below.

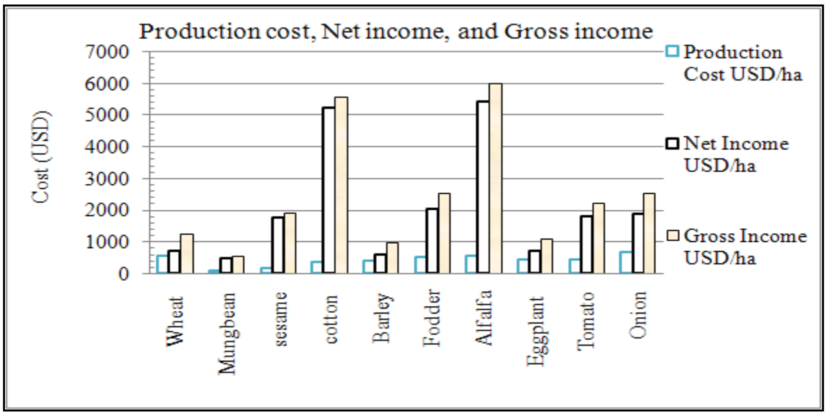


Fig.4.12: Crops Net Income, Production cost and Gross income

4.8 Crops calories content

Refer to table 4.10, the highest calories (Kcal/g) are produced from oil seeds crops (Cotton, Sesame) and tomato is the lowest calories content crop. Mega calories per hectares of cotton and alfalfa respectively are higher than all other crops, because cotton has the highest calories content per gram, and alfalfa is the most productive crop in the study area.

Table.4.10. Calories Content of Study Area Crops

Crops name	Yield (ton/ha)	Dry matter yield (ton/ha)	Calories content (Kcal/g)	Mcal/ha
Wheat	3.0	3.0	3.40	10200
Mungbean	0.9	0.9	0.30	270
sesame	0.8	0.8	8.80	7040
cotton	3.5	1.5	8.85	13275
Barley	2.0	2.0	1.22	2440
Fodder	32.0	6.5	0.24	1560
Alfalfa	100.0	37.5	0.24	9000
Eggplant	11.0	3.1	0.35	1099
Tomato	12.5	1.8	0.18	322
Onion	16.0	3.2	0.40	1280

The data for calories content of different crops has been collected form, USDA National Nutrient Database for Standard References. Dry yield for crops have been collected from Herat Agricultural Department. There is no change in cereal crops, but for the rest of the crops is give as bellow. Alfalfa crop can be cut 5 times per season each time yields 7.5ton/ ha in dry farm, total per year yield can be calculated around 100 tons/ha in dry farm. Clover crop can support 5 times cut per season and each time cut yields 1.3 ton/ha in dry farm, total yield per season can be calculated around 6.5tons/ha in dry farm. Cotton yields around 3.5 tons/ha in a season out of which 1.5 tons/ha is cottons seed. Tomato crop yields around 1.79 ton/ha try tomato at the rate of 7kg of fresh tomato produce 1 Kg dry. Eggplant yields 3.14 ton/ ha in dry farm at the rate of 3.5kg of fresh eggplant produce 1kg in dry farm. Onion yields around 3.2 ton/ha in dry farm at the rate of 5kg of fresh onion gives 1kg of dry onion.

4.9 Estimation of CWR and IWR

Crop water requirement and irrigation water requirement is calculated by using CROPWAT model with irrigation efficiency of 60% and time step of 10 days for different crops grown in the study area. On the other hand, average water demand for different crops and total irrigation water volume has been calculated for whole scheme level and in Uordo-Khan Sub-branch.

Table.4.11: CWR and IWR for different Crops in the study area

Crops Name	Planting Date	Harvesting Date	Period days	Rotation	Eto (mm)/Period	Max, Kc	CWR (mm)/Period	Rainfall (mm)/Period	Effective Rainfall (mm)/Period	IWR (mm) /period	Gross IWR (mm/period) 60% Eff
Wheat	5-Nov	30-May	206	First Crop	543.3	1.15	455.25	202.62	189.03	318.32	530.53
Mungbean	20-Jun	22-Oct	124	Second Crop	928.58	1.10	685.07	0	0	685.07	1141.78
Sesame	20-Jun	30-Oct	132	Second Crop	957.04	1.20	770.92	0	0	770.92	1284.87
Cotton	3-Apr	5-Nov	216	First Crop	1484.76	1.17	1374.78	25.88	24.67	1350.11	2250.18
Barley	5-Nov	30-May	206	First Crop	543.3	1.15	457.37	202.62	189.03	323.01	538.35
Fodder	22-Oct	5-Jul	256	First Crop	898.36	0.90	733.04	202.62	189.03	609.38	1015.63
Alfalfa	6-Oct	6-Oct	perennial	perennial	1693.25	0.95	1470.62	202.62	189.03	1355.53	2259.22
Eggplant	5-Mar	22-Oct	231	First Crop	1516.24	1.05	1345.99	71.49	66.67	1292.19	2153.65
Tomato	3-Apr	22-Oct	202	First Crop	1437.97	1.15	1420.68	25.88	24.67	1396.01	2326.68
Onion	5-Mar	6-Oct	215	First Crop	1444.83	1.05	1377.57	71.49	66.67	1311.92	2186.53

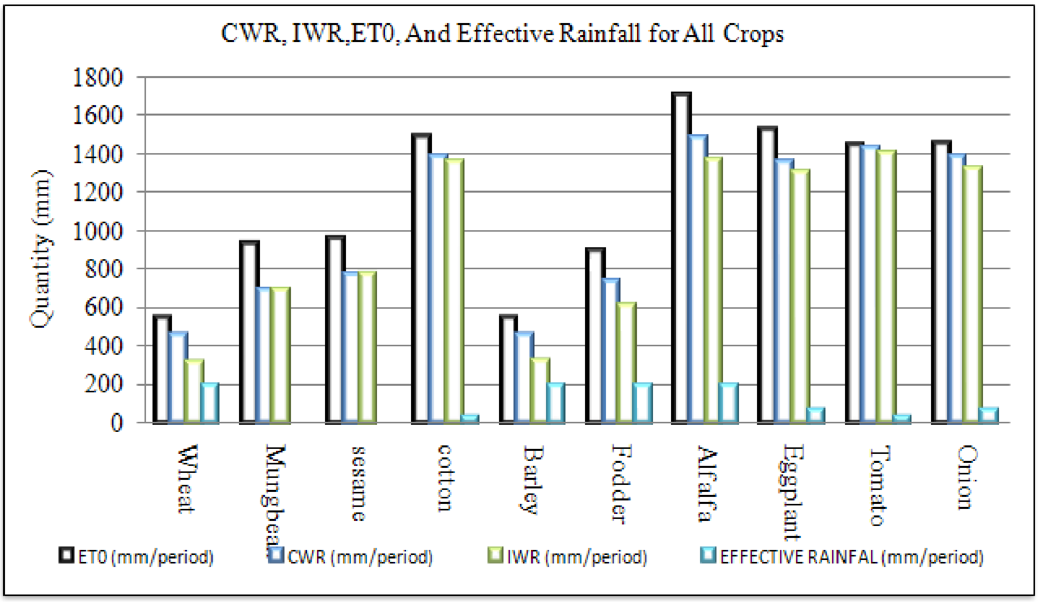


Fig.4.13: Comparison of CWR, IWR, ETo, and Effective rainfall for whole crops

Refer to (fig.4.13) it shows that wheat and barley which are occupied respectively 50 and 12 % of the case study land area, consuming the minimum water respectively 318.3 and 323.01 mm, due to low CWR and high effective rainfall in the study area. Alfalfa has the highest water consumption than others, because it has the longest age than all others, which is calling (Perennial crop). All vegetable crops (Eggplant, Tomato, and, Onion), are almost having similar irrigation requirement. The water requirement for these crops is higher because of high evapotranspiration and less effective rainfall during their age period.

Oil seed crops (Cotton, and Sesame), irrigation requirement for these two crops is totally different because of difference in their cultivable time, cotton is cultivated in 3rd of April, but sesame is a second crop which is normally cultivated after harvesting wheat and barley in 20 June. Herewith, cotton required more irrigation than sesame. Table.4.12 indicates that total net irrigation requirement for entire Jui-Naw scheme and Urodo-Khan sub branch respectively are 19.75 Million m^3 and 1.66 Million m^3.

Table.4.12: Water quantity for entire Jui-Naw irrigation system and & Uordo-Khan branch

Crops Name	Irrigable Area		Cropping Intensity %	Cropped area %	IWR (mm /period)	Total IWR for Case Study Area (Million m^3)	Total IWR for Whole Schem Area (Million m^3)
	Total Irrigable Area m^2	Case Study Area m^2					
Wheat	51330000	4000000	75	50	318.32	0.48	6.13
Mungbean				9	685.07	0.18	2.37
sesame				5	770.92	0.12	1.48
cotton				4	1350.11	0.16	0.50
Barley				12	323.01	0.12	1.49
Fodder				9	609.38	0.16	2.11
Alfalfa				2	1355.53	0.08	1.04
Eggplant				3	1292.19	0.12	1.49
Tomato				3	1396.01	0.13	1.61
Onion				3	1311.92	0.12	1.52
Total	51,330,000	4,000,000	75	100	9412.46	1.66	19.75

Table.4.13: Impact of irrigation efficiency on GIR

Irrigation Effeciency %	Mungbean		sesame		cotton		Alfalfa		Eggplant		Tomato		Onion	
	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %	IWR with different effecincy (mm/period)	Ave GIR which is saved %
10	6850.70	50.00	7079.20	50.00	13501.10	50.00	13555.30	50.00	12921.90	50.00	13960.10	50.00	13119.2	50.00
20	3425.35	33.33	3539.60	33.33	6750.55	33.33	6777.65	33.33	6460.95	33.33	6980.05	33.33	6559.60	33.33
30	2283.57	25.00	2359.73	25.00	4500.37	25.00	4518.43	25.00	4307.30	25.00	4653.37	25.00	4373.07	25.00
40	1712.68	20.00	1769.80	20.00	3375.28	20.00	3388.83	20.00	3230.48	20.00	3490.03	20.00	3279.80	20.00
50	1370.14	16.67	1415.84	16.67	2700.22	16.67	2711.06	16.67	2584.38	16.67	2792.02	16.67	2623.84	16.67
60	1141.78	14.29	1179.87	14.29	2250.18	14.29	2259.22	14.29	2153.65	14.29	2326.68	14.29	2186.53	14.29
70	978.67	12.50	1011.31	12.50	1928.73	12.50	1936.47	12.50	1845.99	12.50	1994.30	12.50	1874.17	12.50
80	856.34	11.11	884.90	11.11	1687.64	11.11	1694.41	11.11	1615.24	11.11	1745.01	11.11	1639.90	11.11
90	761.18	10.00	786.58	10.00	1500.12	10.00	1506.14	10.00	1435.77	10.00	1551.12	10.00	1457.69	10.00
100	685.07		707.92		1350.11		1355.53		1292.19		1396.01		1311.92	
		21.43		21.43		21.43		21.43		21.43		21.43		21.43

Table 4.13 shows the impact of irrigation efficiency on IWR for different crops. Improvement in efficiency by 10% could result to save as average 21.4 % of GIR of different crops. The water required for mungbean in 60% irrigation efficiency is equal to 1141.78 mm/period, but if irrigation efficiency improves to 70 % the water requirement for mungbean fall down to 978.67. It means 14.29 % of required ware could be saved. The techniques to save water through improving irrigation efficiency is the appropriate way to save water to expand the irrigated land, or else the saved water could be used for other economical users aspect.

Table 4.14 accordingly shows the extra land area that could be covered for each crop; of course the crop which need less water could extend in a high coverage than the crop required more water.

Table.4.14 Extra land for different crops based on efficiency improvement

Crops Name	**Total Area (ha)**	**Required water for total area (m^3)**	**Available water due to efficiency improvement (m3)**	**extendable land based on available water (ha)**
Mungbean	27	184680	39576.92	5.79
sesame	15	115566	24765.79	3.21
cotton	12	161772	34667.74	2.57
Alfalfa	6	81449.4	17454.61	1.29
Eggplant	9	116082	24876.37	1.93
Tomato	9	125442	26882.22	1.93
Onion	9	117882	25262.11	1.93
Total	87	1,659,611	193, 485.76	

4.10 Comparison of farmers strategies with the actual condition

The best way for examine farmer's strategies against the actual crop water need for practiced crops is to explore monthly total gross irrigation requirement for all practiced crops and then compare them with monthly canal water supply. Result of this scenario count the scarcity of available water versus actual crops irrigation requirements.

The water demand for different crops is derived with the help of CROPWAT model with a time step of 30 days. Table.4.15 is indicating monthly base field water demand for different crops. Total gross irrigation requirement is calculated with respect to an overall irrigation efficiency of 60 %.

Table.4.15. Monthly net IWR and total gross IWR for practiced crops in the study Area (mm)

Crops Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total IWR (mm)
Wheat	-	26.38	0	0	1.65	51.11	135.72	103.09	-	-	-	-	318
Mungbean	31	-	-	-	-	-	-	-	35.81	163.08	260.6	194.55	685
sesame	71.14	-	-	-	-	-	-	-	53.72	154.62	275.93	215.51	771
cotton	83.74	-	-	-	-	-	27.36	106.68	233.71	316.02	377.07	205.57	1350
Barley	-	13.28	0	0	1.65	51.11	146.45	110.52	-	-	-	-	323
Fodder	13.94	23.33	0	0	0	45.28	129.81	200.56	196.46	-	-	-	609
Alfalfa	70.65	17.99	0	0	0	34.02	118.46	202.68	245.58	256.33	230.57	178.86	1355
Eggplant	89.01	-	-	-	-	0	39.88	154.22	261.61	284.54	260.5	202.44	1292
Tomato	44.82	-	-	-	-	-	64.02	154.04	257.89	311.74	370.58	192.93	1396
Onion	20.29	-	-	-	-	15.21	87.56	190.88	266.77	284.54	260.5	186.16	1312
Net IWR /month	424.6	80.98	0	0	3.3	196.7	749.26	1222.67	1551.6	1770.87	2035.8	1376.02	9412
Gross IWR/month	707.6	135	0	0	5.5	327.9	1248.8	2037.8	2585.9	2951.45	3392.9	2293.37	15686

To understand the actual field situation, table 4.15 is multiplied with the cropped area in Uordo- khan canal; of course field cropping intensity is considered as well. Table 4.16 is depicting net required quantity of water in different months in the study area and total monthly gross quantity of water with respect to 60 % irrigation efficiency.

Table.4.16: Actual monthly water requirement of different crops in the study area (m³)

Crops Name	Net cultivated area(m²)	Crop area (%)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total IWR (m³)
Wheat	3,000,000	50	-	39600	0	0	2475	76650	203550	154500	-	-	-	-	476775
Mungbean		9	8370	-	-	-	-	-	-	-	9720	44010	70200	52380	184680
sesame		5	10671	-	-	-	-	-	-	-	8055	23190	41250	32400	115566
cotton		4	10044	-	-	-	-	-	3288	12720	27960	37920	45240	24600	161772
Barley		12	-	4788	0	0	594	18396	52560	39600	-	-	-	-	115938
Fodder		9	3753	6291	0	0	0	12231	34830	54000	52920	-	-	-	164025
Alfalfa		2	4590	1079	0	0	0	2040	7080	12120	14700	15360	13800	10680	81449
Eggplant		3	8010	-	-	-	-	0	3582	13860	23490	25560	23400	18180	116082
Tomato		3	4032	-	-	-	-	-	5760	13860	23220	27990	33300	17280	125442
Onion		3	1827	-	-	-	-	1368	7884	17100	24003	25560	23400	16740	117882
Total	3,000,000	100	51297	51758	0	0	3069	110685	318534	317760	184068	199590	250590	172260	1,659,611
Total monthly Gross Flow Rate with 60% Irr efficiency			85,495	86,264	0	0	5115	184475	530,890	529,600	306,780	332,650	417,650	287,100	2,766,019

Total irrigable area* Cropping intensity = Net cultivated area, Total Case Study Area= 400 ha, Cropping Intensity = 75 %, Hence, Net cultivated area = 400*0.75= 300 ha, Total Gross Irrigation Flow Rate = Total monthly IWR (m3) / Irrigation Efficiency

Table.4.17. Comparison of the monthly available canal flow with gross irrigation requirement

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Monthly Net field water Demand (m^3)	51297	51758.4	0	0	3069.0	110685	318534	317760	184068	199590	250590	172260
Monthly Gross field Water Demand (m^3)	85495	86264	0	0	5115.0	184475	530890	529600	306780	332650	417650	287100
Monthly Canal Available Water (m^3)	177497.6	171771.8	267304.3	357298.6	322721.3	640994.7	894862	924691	510080	129474	129474	148522
RWS	2.08	1.99	_	_	63.1	3.47	1.69	1.75	1.66	0.39	0.31	0.52

Table.4.17 is presenting the summary of Table 4.16 and canal monthly available water, that is calculated on account of a rectangular weir, according Francis's formula for different seasons and months, net IWR that is derived monthly based with the help of CROPWAT model, and gross IWR, which is calculated with respect of 60% of overall irrigation efficiency.

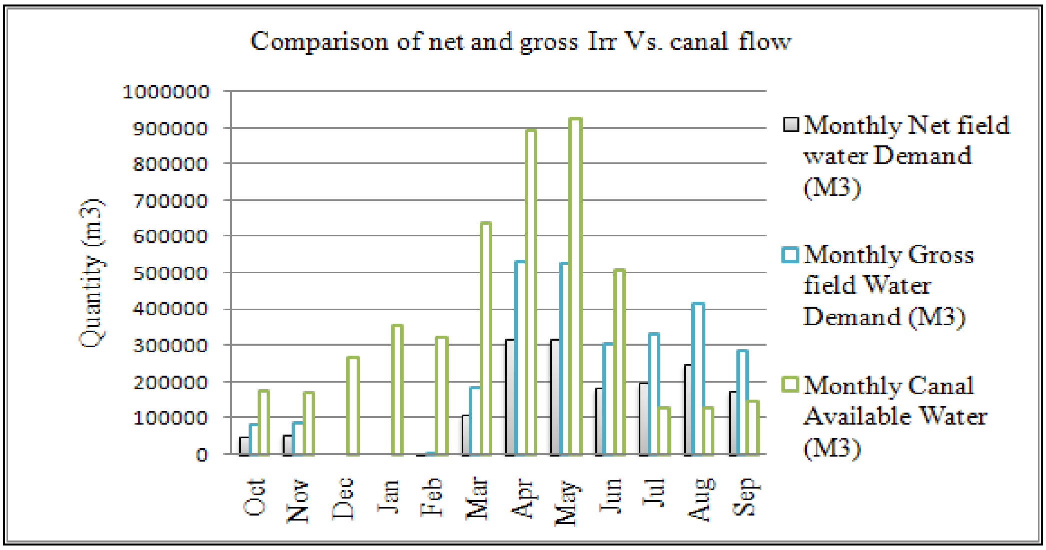


Fig.4.14. Comparison of current irrigation water supply and demand in the study area

Figure.4.14 describes clearly the water shortages during July, August, and September for the crops that are cultivated after May in the study area. August has the highest water shortages than July and September. In August the gross irrigation water demand for all practiced crops in the study area is (0.417Million m^3), but the canal flow rate is (0.129 Million m^3), which is showing 69 % water deficit than what is required to be supplied for the practiced crops.

Figure 4.15 illustrates the comparison of effective rainfall Vs, evapotranspiration in the area of study that is depicting some valid reason of water shortage in the canal during the observed months. High temperature during summer, low rainfall, and high evapotranspiration are the major cause of this shortage.

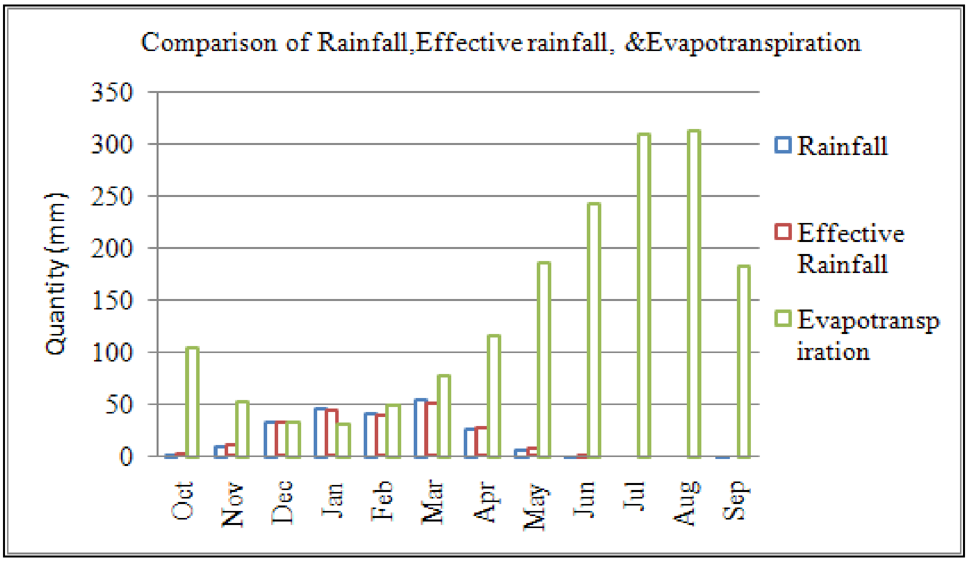


Fig.4.15: Comparison of Rainfall, Effective Rainfall and Evapotranspiration

Thus, according to current demand and supply it is proofed that, farmers are not able to make satisfy their cropped lands demand with the available canal supply. Though, farmer's approaches seem correct in case of water shortage to bring down cropping intensity, it means do not cultivate all available area therefore, current cropping intensity is fallen down to 75% by the farmers. But still farmers do not know the optimal situation with respect to the available resources, current results indicates that famers are accepting unknown yield reduction in their fields. The next objectives of this study give the optimal cropping system options in account of different scenarios.

4.11 Cropping System Scenarios

To quantify the possible cropping system three scenarios are considered.

- Reducing area of all crops towards optimal supply of water, and IWR satisfaction,
- Eliminating some crops towards optimal supply of water, and IWR satisfaction, and last
- keeping all crops but with sub-optimal supply of water

4.11.1 Reducing Area of All Crops and Optimal Supply of Water

The general idea is that water should be utilized optimally to maximize the net benefits and satisfy the calories demand with respect to the supply and demand. The first step is considered for finding the sensitive stage of all the crops faced water shortages during the age of the crops. Hence, by using the result from Figure 4.14 it is clear that all the practiced crops, which are cultivated after May are facing shortfall during July, August and September.

The aim of the first scenario is to reduce the cropped area to some extent to all for being able to satisfy the demand with the available supply. With consideration of relative water supply the land is allocated as shown in table 4.18. Moreover, the maximum total monthly crops water demand is derived here from table, 4.17 and then divided by the 60 % irrigation efficiency to gain monthly gross income.

Table.4.18 Land allocation with the calculation of RWS, to maximize NB & Cal. outcome

Crops Name	Initial Croped Land, ha	Max, Gross water Demand m^3 /mon	Min, Canal Supply m^3/mon	RWS	Allocated Land based on RWS ha	Net Income USD / ha	Net Benefites, USD	Calories content, Mac/ha	Net calories production, Macl
Mungbean	27.0	117000.0	129473.90	0.303	8.18	449.82	3679.53	270.00	2208.60
sesame	15.0	68750.0			4.54	1776.90	8067.13	7040.00	31961.60
cotton	12.0	75400.0			3.63	5242.20	19029.19	13275.00	48188.25
Alfalfa	6.0	25600.0			1.82	5446.80	9913.18	9000.00	16380.00
Eggplant	9.0	42600.0			2.73	686.20	1873.33	1099.00	3000.27
Tomato	9.0	55500.0			2.73	1802.20	4920.01	322.20	879.61
Onion	9.0	42600.0			2.73	1883.60	5142.23	1280.00	3494.40
Total	87.0	427450.0	129473.9	0.303	26.35		52624.58		106112.73

RWS = $\sum$ Min, Water Supply/ Max, Demand = 129473.9 /427450 = 0.303
Land Allocation for Mungbean based on RWS= 0.303*27= 8.18 ha
Net income and calories content calculation of practiced crop respectively referred to table (4.9) and (4.10).

According to the result in (Table.4.18), the overall area is reduced in a very high extent from 87 hectare to 26.35 hectare, which indicates an overall 69.7% area reduction due to water availability limitation, and the remaining land are allocated to the crops back along with the consideration of available water. Result of new land allocation for the practiced crops is tested with respect to the net income and calories production as well. The overall net income and calories production can be gained with this scenario respectively are USD52623.69 and 106112.73 mega calories. Mungbean which is the only crop occupying more land than all others shows a very less income and calories production due to the other crops. But among all the practiced crops cotton and alfalfa are showing significant high economic return and calories production in their area of cultivation.

4.11.2 Eliminating Some Crops and Optimal Supply of Water

The main concept of second scenario is to eliminate some crops, to adjust the current land according the available water supply. Optimization technique is used to maximize net economic return (NER), calories production, and to minimize the fertilizer and labor under limited water supply for identifying the cropping system options. Linear programming is used to model scenarios to allocate the available resource like, water, land, labor, irrigation, and fertilizer in the best possible manner so to gain maximum profit. Two scenarios have been developed for maximization, and two for minimization to help for the right decision in the study area. Quantitative System for Business (Win-QSB), which is an optimization technique tool that use simplex algorithm, has been used to help for the problem solution. The scenarios bellow are modeled such as, constraints imposed on the objective function to be incorporate components that account for farmers preference important on the area of cultivation.

- Maximizing the net economic return (NER) based on the resource availability.
- Maximizing the calories producing due to available constraint.
- Minimizing the fertilizers for different crops kilograms per hectares.
- Minimize the labor force per hectare of the cultivated lands.

Bellow table 4.19 shows all resource availability and limitation for the crops in the study area. Gross irrigation water requirement (m^3/month/ ha) for each crop is selected based on maximum demand of water in months of July, August and September.

Table.4.19 Resource availability and limitation for all the crops in study area

Crops Name	Resorce availability and limitaion for the Crops									
	Gross water requirment m3/month/ha	Land (ha)	Tota water m^3/month	Tota land (ha)	Fertilizer kg/ha	Labor for land pers/ha	Seed kg/ha	Irrigation labor pers /ha	Benefits ($/ha)	Calories Mcal/ha
Mungbean	4333.3	27	129473.9	87	65	10	15	5	449.82	270.00
Sesame	4583.3	15			100	15	6	7	1776.90	7040.00
Cotton	6283.3	12			250	50	14	20	5242.20	13275.00
Alfalfa	4266.7	6			150	65	20	30	5446.80	9000.00
Eggplant	4733.3	9			220	40	0.25	16	686.20	1099.00
Tomato	6166.7	9			250	45	0.3	20	1802.20	322.20
Onion	4733.3	9			300	75	15	35	1883.60	1280.00

The objective function of the model for maximizing the net income is formulated based on all crops cultivated in the study area.

$Z = \sum NBiXi$ Where, NBi = Net benefits from Xi   i = 1, 2… 7
Let x1 = cultivable area (ha) for Mungbean
Let x2 = cultivable area (ha) for Sesame
Let x3 = cultivable area (ha) for Cotton
Let x4 = cultivable area (ha) for Alfalfa
Let x5 = cultivable area (ha) for Eggplant

Let x6 = cultivable area (ha) for Tomato
Let x7 = cultivable area (ha) for Onion
Thus, mathematically we can present the objective function as bellow

Max Z= $449.82X_1 + 1776.9X_2 + 5242.2X_3 + 5446.8X_4 + 686.2X_5 + 1802.2X_6 + 1883.$

Constraints

(1) Constraints due to irrigation water requirement (Water, M^3/Month/ha): Gross irrigation water requirement should be less than or equal to the available water during the shortage period, Jul, Aug, and Sep.
4333.3X1 + 4583.3X2+ 6283.3X3 + 4266.7X4+ 4733.3X5+ 6166.7X6+4733.3 X7 <= 129473.9

(2) Constraint due to fertilizer requirement of each crop (Kg/ha): Fertilizer requirement should be greater or equal to the total land available multiply to the minimum fertilizer which is used to any crop. (87*65= 5655). It shows that 65 ha cultivated by mungbean require 5655Kg of fertilizers which is the minimum requirement than other crops in the study area.
$65X_1 + 100X_2 + 250X_3 + 150X_4 + 220X_5 + 250X_6 + 300X_7 >= 5655$

(3) Constraint due to labor requirement of each crop (Person/ha): It should be greater or equal to the total land available multiply by the minimum labor requirement for a crop the minimum labor.(87*10=870), it means if we cultivate the total land area with mungbean crop 870 person is required ,which is the less labor work on the field than the other crops, so
$10X_1 + 15X_2 + 50X_3 + 65X_4 + 40X_5 + 45X_6 + 75X_7 >= 870$

(4) Constraint due to seed requirement of each crops (Kg/ha): It should be greater or equal to the total land available multiply by the minimum crop seed which is required, (87*0.25=22), it means if we cultivate the total land area with eggplant, 22Kg seed is required ,which is the less seed than the other crops, so
15X1 + 6X2+ 14X3 + 20X4+ 0.25X5+ 0.3X6 + 15X7 >= 22

(5) Constraint due to irrigation labor requirement of each crop (Person/ha): It should be greater or equal to the total land available multiply by the irrigation labor for a crop which requires minimum number of labor.(87*5=435 person), it means if we cultivate the total land area by the mungbean crop 435 person is required, that is the less number of labor than the other crops irrigation labor requirement , so
5X1 + 7X2 + 20X3 + 30X4 + 16X5 + 20X6 + 35X7 >= 435

(6) Constraint due to land availability for each crop (ha): The sum of cropped area cannot
$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_{13} <= 87$

(7) Constraints due to calories production (Mcal/ha): It should be greater or equal to the total available land multiply by the multiplier of a crop which is produced minimum calories, (87*270=23490), it means if we cultivate the total land area with mungbean crop than 23490 mega calories would be produced, which is the lowest calories production compare to other crops.
$270X1 + 7040X2 + 13275X3 + 9000X4 + 1099X5 + 322.2X6 + 1280X7 >= 23490$

(8) Non-negative constraints: The model has applied different value for the land until it reached to an optimal one, herewith all crops land area should be greater or equal to the zero.
$X_1, X_2, X_3, X_4, X_5, X_6, X_7 >= 0$

The bellow result in table (4.20) shows that, for adjusting the highest economic return and calories production it is required to keep 21.1 ha alfalfa, 8.3ha onion, out of 87 ha, and the rest all should be eliminated from the copping system. The net benefits and calories production in this scenario is showing 40.18 % and 52.73% respectively increment than the first scenario (Reducing area of all crops towards optimal supply of water).

Table.4.20: Land allocation, with respect to give up crops to gain max NB

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	449.8	0	-7800.96	at bound	_ M	8250.76
Sesame	0	1776.9	0	-5977.06	at bound	_ M	7753.96
Alfalfa	21.18	5446.8	115386.5	0	basic	3925.27	M
Cotton	0	5242.2	0	-1872.93	at bound	_ M	7115.14
Eggplant	0	686.2	0	-3687.8	at bound	_ M	4374
Tomato	0	1802.2	0	-5036.48	at bound	_ M	6838.68
Onion	8.26	1883.6	15554.5	0	basic	-6713.6	6042.45
Objective	Function	(Max.) =	130941				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
fertilizer	5655	>=	5655	0	-31.13	4551.78	8206.15
seed	547.55	>=	22	525.55	0	_ M	547.55
Calories	201229	>=	23490	177739	0	_ M	201228.6
C.Labor	1996.32	>=	870	1126.32	0	_ M	1996.32
I. Labor	924.55	>=	435	489.55	0	_ M	924.55
Water	129474	<=	129473.9	0	2.37	89222.7	160854.6
Land	29.44	<=	87	57.56	0	29.44	M

(Right Hand Side) is showing the limit resource which was defined for each crop, but (Left hand Side) is indicating the optimal situation according to the constraint, maximum calories can be produced from this scenario is listed in (Left Hand Side) equal to 201229 mega calories. Furthermore, surplus values are showing the difference between left and right side. The shadow price is showing that 2.37 unit of water can increase one more unit land under the cultivation.

One scenario is developed only for the crops which direct fulfill food requirements. Table 4.21 indicates that, the only crop can give the maximum income whenever to eliminate alfalfa and cotton is onion, to allocate 27.35 ha land out of 87ha for onion the maximum outcome could be achieved that is USD 51523.68. A reduction of 39.35 % in maximum net income and 17.4 % in calories production would occur than the first scenario that is given in Table 4.20.

Table.4.21: Land allocation, without consideration of (Alfalfa and Cotton) to max NB

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	449.8	0	-1274.62	at bound	_ M	1724.421
Sesame	0	1776.9	0	-47.008	at bound	_ M	1823.908
Eggplant	0	686.2	0	-1197.4	at bound	_ M	1883.6
Tomato	0	1802.2	0	-651.817	at bound	_ M	2454.017
Onion	27.3538	1883.6	51523.68	0	basic	1835.054	M
Objective	Function	(Max.) =	51523.68				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
fertilizer	8206.15	>=	5655	2551.15	0	_ M	8206.15
seed	410.3075	>=	22	388.308	0	_ M	410.3075
Calories	35012.91	>=	23490	11522.9	0	_ M	35012.91
C.Labor	2051.538	>=	870	1181.54	0	_ M	2051.538
I. Labor	957.3842	>=	435	522.384	0	_ M	957.3842
Water	129473.9	<=	129473.9	0	0.3979	89222.7	411797.1
Land	27.3538	<=	87	59.6462	0	27.3538	M

The first scenario was the indicator of maximum calories production as well as net income with the consideration of all cropping system. Thus one more scenario is developed for calories maximization in the study area without consideration of alfalfa and cotton to prioritize the crops which direct fulfill people food requirements. Following the mathematical form of this scenario is written bellow.

$Z = \sum Cal\ Xi$ Where, Cali = calories produced form Xi   i = 1, 2… 7

Max Z=270X1 + 7040X2 + 13275X3 + 9000X4 + 1099X5 + 322.2X6 + 1280X7

All constraint would be the same as NER scenario just here instead NB calorie is replaced, and NB objective function will take place as a constraint.

Table.4.22: Land allocation, without consideration of (Alfalfa and cotton) to max calories

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	270	0	-7,285.66	at bound	_ M	7,555.66
Sesame	13.3924	7,040.00	94,282.25	0	basic	1,239.44	M
Eggplant	0	1,099.00	0	-2,617.02	at bound	_ M	3,716.02
Tomato	0	322.2	0	-5,634.35	at bound	_ M	5,956.55
Onion	14.3859	1,280.00	18,413.92	0	basic	-3,130.62	7,270.40
Objective	Function	(Max.) =	112,696.20				
Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
fertilizer	5,655.00	>=	5,655.00	0	-30.4503	4,505.62	8,206.15
seed	296.1424	>=	22	274.1424	0	_ M	296.1424
Net income	50,894.13	>=	39,132.60	11,761.53	0	_ M	50,894.13
C.Labor	1,279.83	>=	870	409.8264	0	_ M	1,279.83
I. Labor	597.2523	>=	435	162.2523	0	_ M	597.2523
Water	129,473.90	<=	129,473.90	0	2.2004	98,709.19	233,971.30
Land	27.7782	<=	87	59.2218	0	27.7782	M

The result for this scenario has given above in table 4.22 that indicates without cotton and alfalfa, the highest calories achieve whenever to allocate 13.39 ha to sesame and 14.39 ha out of 87ha area. The calorie production goes down in study area because cotton and alfalfa contributes high calories to the cropping system. To remove alfalfa and cotton 56 % deduction would be arise than the scenario has been developed with all crops, which is given in table 4.20.

To allocate the available lands to the crops which are using the minimum fertilizer, a minimization model has been developed; bellow is the mathematical expression of the model.

$Z = \sum FiXi$ Where, Fi = Fertilizer required for Xi $i = 1, 2\ldots 7$

$$\textbf{Min } Z = 65X_1 + 100X_2 + 250X_3 + 150X_4 + 220X_5 + 250X_6 + 300X_7$$

The constraints for this scenario are similar to the previous one; merely fertilizer is moved as an objective function and the rest all are presented as constraints

Table 4.23: Land allocation due to minimum fertilizer consumption

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	65	0	40	at bound	25	M
Sesame	0	100	0	65	at bound	35	M
Alfalfa	14.5	150	2175	0	basic	0	257.1429
Cotton	0	250	0	150	at bound	100	M
Eggplant	0	220	0	140	at bound	80	M
Tomato	0	250	0	150	at bound	100	M
Onion	0	300	0	125	at bound	175	M
Objective	Function	(Min.) =	2175				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
Net income	78978.59	>=	39132.6	39846	0	_ M	78978.59
seed	290	>=	22	268	0	_ M	290
Calories	130500	>=	23490	107010	0	_ M	130500
C.Labor	942.5	>=	870	72.5	0	_ M	942.5
I. Labor	435	>=	435	0	5	401.5385	910.3562
Water	61867.15	<=	129473.9	67606.7	0	61867.16	M
Land	14.5	<=	87	72.5	0	14.5	M

The result in table 4.23 indicates that, 2175 kilogram fertilizer is the minimum amount, whenever to allocate 14.5 ha to alfalfa crop and the rest all should be zero. Same scenario has been developed without alfalfa and cotton to minimize the fertilizer usage in the area of study based on the available constraints. The result is shown in table 5.24.

Table 4.24: Land allocation due to minimum fertilizer, without (Cotton and alfalfa)

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	65	0	16.9803	at bound	48.0197	M
Sesame	11.2287	100	1122.866	0	basic	60	211.5645
Eggplant	0	220	0	87.8529	at bound	132.1471	M
Tomato	0	250	0	57.8353	at bound	192.1647	M
Onion	10.1828	300	3054.852	0	basic	106.0048	423.6463
Objective	Function	(Min.) =	4177.718				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
Net income	39132.6	>=	39132.6	0	0.0286	24975.22	50610.5
seed	220.1145	>=	22	198.1145	0	_ M	220.1145
Calories	92083.8	>=	23490	68593.8	0	_ M	92083.8
C.Labor	932.1429	>=	870	62.1429	0	_ M	932.1429
I. Labor	435	>=	435	0	7.034	406	727.1401
Water	99662.74	<=	129473.9	29811.15	0	99662.74	M
Land	21.4115	<=	87	65.5885	0	21.4115	M

To allocate in order 11.23 ha and 10.18 ha respectively to sesame and onion the minimum fertilizer requirements would be achieved, which is 4177.72kilograms. The first scenario with consideration of alfalfa and cotton is showed 52.06 % reduction than this scenario.

For allocating the available lands to the crops that are using the minimum labor for the crops, a minimization model has been developed; bellow is the mathematical expression of the model.

$Z = \sum CLXi$ Where, CLi = Crops labor required for Xi   i = 1, 2… 7

Min $\mathbf{Z = 10X_1 + 15X_2 + 50X_3 + 65X_4 + 40X_5 + 45X_6 + 75X_7}$

For this scenario all constraints are similar to the pervious scenarios, just here crops labor requirement is changed to objective function and the rest all demonstrated as constraint.
The result in table (4.25) which is given bellow, shows that, to minimize the labor force for the crops, out of 87 ha land is allocated to 1.7 ha, 15.8 ha, and 5.1 ha respectively for sesame, tomato and onion and the minimum solution for this scenarios is 1119.8 person

Table.4.25: land allocation based on minimum labor requirements of crops

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	10	0	11.04	at bound	-1.04	M
Sesame	0	15	0	5.86	at bound	9.14	M
Alfalfa	0	65	0	18.53	at bound	46.47	M
Cotton	3.09	50	154.35	0	basic	44.63	65.05
Eggplant	13.5	40	539.92	0	basic	36.66	43.63
Tomato	7.2	45	323.86	0	basic	40.58	47.31
Onion	0.38	75	28.61	0	basic	60.44	93.99
Objective	Function	(Min.) =	1046.75				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
fertilizer	5655	>=	5655	0	0.21	5416.04	5835.17
seed	54.48	>=	22	32.48	0	_ M	54.48
Calories	58622.41	>=	23490	35132.41	0	_ M	58622.41
Net income	39134.3	>=	39134.3	0	0	31349.87	60708.63
I. Labor	435	>=	435	0	0.84	428.36	476.05
Water	129473.9	<=	129473.9	0	0	123786.3	132226.4
Land	24.16	<=	87	62.84	0	24.16	M

Out of 87 ha, total land that is allocated in order 3.09ha, 13.5 ha, 7.2ha and 0.38 ha respectively for cotton eggplant, tomato and onion and the minimum solution for this scenario is 1046.75 person.

Similarly, one scenario is considered without alfalfa and cotton to minimize the labor requirement in the area of study based on the available constraints, the result for this scenario is presented in table 4.26.

Table.4.26 land allocation based on minimum labor (without Alfalfa & cotton)

Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
Mungbean	0	10	0	20.74	at bound	-10.74	M
Sesame	1.51	15	22.72	0	basic	6.44	207.16
Eggplant	2.23	40	89.34	0	basic	31.51	46.11
Tomato	14.8	45	665.78	0	basic	31.85	49.45
Onion	4.38	75	328.34	0	basic	58.89	M
Objective	Function	(Min.) =	1106.18				
	Left Hand		Right Hand	Slack	Shadow	Allowable	Allowable
Constraint	Side	Direction	Side	or Surplus	Price	Min. RHS	Max. RHS
fertilizer	5655	>=	5655	0	0.33	5256.53	6625.35
seed	79.75	>=	22	57.75	0	_ M	79.75
Calories	23490	>=	23490	0	0	11055.07	86563.16
Net income	39134.3	>=	39134.3	0	0.01	29161.02	41124.51
I. Labor	495.47	>=	435	60.47	0	_ M	495.47
Water	129473.9	<=	129473.9	0	-0.01	115391.5	139900.8
Land	22.92	<=	87	64.08	0	22.92	M

To allocate the available land based on minimization of crops labor requirement cotton and alfalfa were not considered in this scenario. The result found 5.37 % increment in minimization of objective function. Due to this scenario a total of 22.92ha land is allocated to sesame, eggplant, tomato and onion respectively 1.51, 2.23, 14.8, and 4.38 hectares.

4.11.3 Keeping All Crops with Sub-Optimal Supply of Water

The objective of this scenario is to keep current cultivable land with sub-optimal supply and compare the results with the other scenarios with respect to net income and calories production point of views.

Table 4.27 is given below summarizes the information, which is computed for applying optimal supply of irrigation water during the months which crops are faced water shortages in the study area. To compare optimal situation with sub-optimal, Jul, Aug, and Sep are only months that practiced crops faced water limitation refer to Figure 4.15.

Table.4.27 Yield, Calories and Net income, in case of optimal water supply for all area

Crops	Area (ha)	Irrigation water requirement (mm)			Yield ton/ha	Mcal/ha	Net USD/ha	Yield Reduction %
		Jul	Aug	Sep				
Mungbean	27	163.08	260.60	194.55	0.9	270.0	449.82	0
sesame	15	154.62	275.93	215.51	0.8	7040.0	1776.90	0
cotton	12	316.02	377.07	205.57	3.5	13275.0	5242.20	0
Alfalfa	6	256.33	230.57	178.86	100.0	9000.0	5446.80	0
Eggplant	9	284.54	260.50	202.44	11.0	1099.0	686.20	0
Tomato	9	311.74	370.58	192.93	12.5	322.2	1802.20	0
Onion	9	284.54	260.50	186.16	16.0	1280.0	1883.60	0
Total	87	1770.87	2035.75	1376.02				

The current amount of available irrigation water for the same three months in the field was calculated for each crop based on relative water supply. Relative water supply for each month was computed through dividing total available water supply in each month by total gross water demand for each month in the field. Table 4.28 provides a view of the ratio found for each month. The table signifies that RWS ratio in July, August and September was 0.4, 0.3 and 0.5 respectively, which are indicating that supply is not enough to meet the demand of 87 ha cultivated land.

Table 4.28 Relative water supply

Months	Monthly gross field water demand (M^3)	Monthly canal available water (M^3)	RWS
Oct	85460	177497.6	2.1
Nov	86264	171771.8	2.0
Dec	0	267304.3	-
Jan	0	357298.6	-
Feb	5115	322721.3	63.1
Mar	184475	640994.7	3.5
Apr	529020	894862.1	1.7
May	529600	924690.8	1.7
Jun	306630	510079.7	1.7
Jul	332650	129473.9	0.4
Aug	417650	129473.9	0.3
Sep	287100	148521.6	0.5

The available amount of water supply for three months was computed by relative water supply multiplied by the actual demand of water in each month in the field. For example RWS for month Jun has been calculated equal to 0.4 and the actual IWR for mungbean in Jul is equal to 163.0.8 mm, hence due to available water supply only water which is available for this crop in month Jul is equal to (163.08*0.4 = 65.23 mm). Table 4.29 and 4.30 provides a view of the analysis carried out for applying the available supply of water for the existing land area. For calculating calories production dry matter yield reduction is considered as well as production cost reduction for calculating the net income.

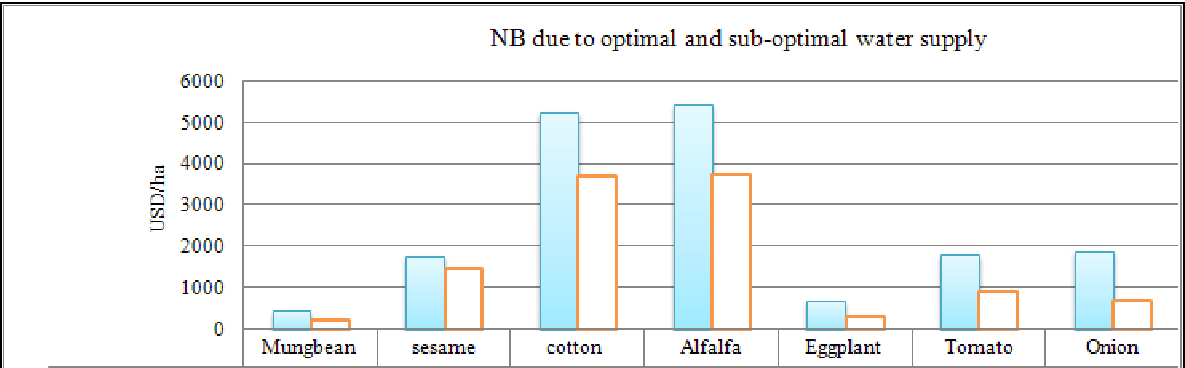
Table.4.29 Yield and Net benefits reduction based on irrigation scheduling of AWS

Crops Name	Cropped Land, ha	Irrigation Water Requirement (mm)			Yield Reduction %	Yield ton/ha	Net Income USD / ha	Net Income USD
		Jul	Aug	Sep				
Mungbean	27	65.2	78.2	97.3	39.8	0.54	233.82	6313.14
sesame	15	61.8	82.8	107.8	14.7	0.68	1488.90	22333.50
cotton	12	126.4	113.1	102.8	27.4	2.54	3706.20	44474.40
Alfalfa	6	102.5	69.2	89.4	28.1	71.90	3760.80	22564.80
Eggplant	9	113.8	78.2	101.2	35.1	7.14	300.20	2701.80
Tomato	9	124.7	111.2	96.5	39.6	7.55	911.20	8200.80
Onion	9	113.8	78.2	93.1	46.8	8.51	685.20	6166.80
Total	87	708.3	610.7	688.0				112755.24

The available supply of water was applied to the same land area through the help of CROPWAT model, irrigation scheduling is developed for the crops which are facing shortage during the July, August and September with respect to the current canal supply, the detail result is demonstrated in the Appendix B. From the result it has been found that, due to water shortfall crops are facing reduction in yield which is causing to reduce the net income and calories production as well.

Table.4.30 Calories reduction with sub-optimal water supply scenario

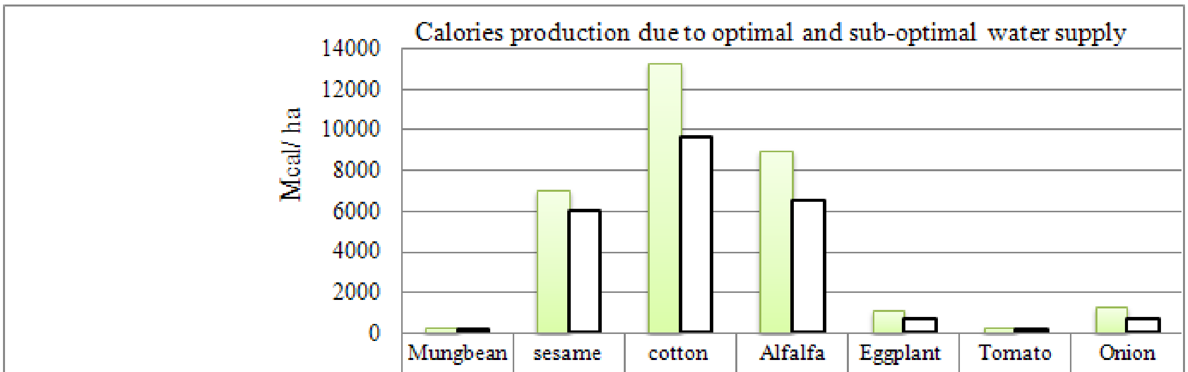
Crops	area, ha	Dry yield ton/ha	Calories content Kcal/g	Calories content Mcal/ha	Calories Production Mcal
Mungbean	27	0.54	0.30	162.0	4374.0
sesame	15	0.68	8.80	5984.0	89760.0
cotton	12	1.09	8.85	9646.5	115758.0
Alfalfa	6	26.96	0.24	6470.4	38822.4
Eggplant	9	2.04	0.35	714.0	6426.0
Tomato	9	1.08	0.18	194.4	1749.6
Onion	9	1.70	0.40	680.0	6120.0
Total	87				263010.0



	Mungbean	sesame	cotton	Alfalfa	Eggplant	Tomato	Onion
NB (optimal water) USD/ha	449.82	1776.9	5242.2	5446.8	686.2	1802.2	1883.6
NB (Sub-optimal) USD/ha	233.82	1488.9	3706.2	3760.8	300.2	911.2	685.2

Fig. 4.16 Comparison the net income due to optimal and sub-optimal water supply

The data indicates that yield in the case of optimal water supply was 0.90 tons per hectare from mungbean crop whereas the yield obtained in case of sub-optimal water supply was decreased to 0.54 tons per hectare that around 39.8% reductions has been found in yield of mungbean crop as a result 108 Mcal/ha calories and 216 USD/ha was decreased. For comparison different scenarios figure (4.16 and 4.17) are given that, provides a complete view for the analysis of all crops within optimal and sub-optimal water supply condition.



	Mungbean	sesame	cotton	Alfalfa	Eggplant	Tomato	Onion
Cal With optimal water supply Mcal/ha	270	7040	13275	9000	1099	322.2	1280
Cal With Sub-optimal water supply Mcal/ha	162	5984	9646.5	6470.4	714	194.4	680

Fig. 4.17 Comparison the calories production due optimal and sub-optimal water supply

Scenario one was considered with reducing area under cultivation of all crops with an optimal supply of water which is explained in detail in section 4.11.1. The outcome of the scenario expresses that if the area under the cultivation of all crops is reduced based on the current available water supply the total land area is reducing from 87 ha to 26.35 ha and the total income and calories produced from all crops of the area cultivated respectively are USD 52624.55 and 106112.73 Mcal.

The section 4.11.2 details the second scenario in which some crops are giving less income and low calories were eliminated through the optimization technique with the consideration of all available resources and constraints. It was concluded that after analysis with Win-QSB, the total area of 29.44 hectares was allocated in order to alfalfa and onion respectively 21.18 and 8.26ha with around USD 130941 total net income and 201229 Mcal productions. Furthermore, two scenarios are developed for maximization of NB and calories production without consideration of alfalfa and cotton, only crops which direct fulfill food requirements was taken in account. In additional two scenarios are developed for land allocation based on minimization of fertilizer and crop labors requirement.

The third scenario was carried out by keeping total existing land with all crops under cultivation in the area. It was found in this scenario that the total 87 ha land under cultivation of all crops presently practiced in the area is giving around USD 112755.24 net incomes and produce calories of 263,010 Mcal. Section 4.11.3 expresses this scenario in detail.

The last scenario to keep all crops with Sub- optimal water supply is the feasible than optimal scenario with area reduction, but second scenario to eliminate some crops with optimal water supply has the highest net benefits than both first and last scenario. In terms of calories third scenario is produced the highest calories than first and second scenarios.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study investigates cropping system options in context of irrigation water scarcity. It aims at improving irrigation water allocation with the objectives of maximizing net economic return and calories production, and minimizing selected production factors. CWR and IWR for all practiced crops are estimated for the study area based on local climatic and cropping system information. Current field situation, as per farmers' practices and water availability, is quantified in terms of demand and supply, and compared with the actual crop water needs. Different scenarios are tested including different possible cropping systems under optimal and sub-optimal water supply. Current farmers' strategy consists in keeping all crops under deficit irrigation and area reduction due to water limitation, and all scenarios are compared for selecting the best option for maximizing NER and Cal production.

The CROPWAT model is used to determine CWR and IWR for all practiced crops in the study area. The gross irrigation requirement is calculated on the basis of different irrigation efficiencies with 10-day time step in the study area for all practiced crops. Results show that 10% improvement in irrigation efficiency result in saving average 21.4% GIR for each practiced crop in the area. Consequently different size of irrigated land area can be expanded for different crops.

Comparison of the farmers crop planning and actual water availability has been done with the help of CROPWAT model and canal flow estimation on monthly basis through field observation, result shows relative water supply (RWS) for July, August, and September are 0.4, 03, and 0.5 respectively, which indicates 60, 70, and 50% water shortage in same months for those crops grown after May. The reasons for water shortage are high evapotranspiration and lack of rainfall at that time.

Possible adjustments of cropping system are investigated through different scenarios:

- Reducing area of all crops towards optimal supply of water, and IWR satisfaction,
- Eliminating some crops towards optimal supply of water, and IWR satisfaction,
- Keeping all crops but with sub-optimal supply of water (deficit irrigation, as practiced by farmers).

In the first scenario, areas of all crops are reduced proportionally by 30.3 % to adjust the overall supply to meet the amalgamated demand. The maximum net benefit and Cal outcome of this scenario are USD 52,625, and 106,113 Mcal respectively.

The second scenario is implemented through linear programming as an optimization technique that uses simplex algorithm, to identify the cropping system option, through the maximization of net economic return (NER), calories production, and minimization of fertilizer and crop labor requirements.

The last scenario tries to investigate the strategy implemented by farmers through deficit irrigation on all crops and to inquire its outcome. Irrigation scheduling is developed for the crops which are facing shortage during the July, August, and September with respect to the current canal supply. The results indicate that due to water shortfall crops are facing reduction in yield which is inducing to reduce the net income and calories production as well in the study area.

Results show that second scenario (elimination of some crops and optimal water supply) is providing 13.89% and 59.8 % higher net economic return than first and third scenarios which are respectively,

- Reducing area of all crops towards optimal supply of water and
- Keeping all crops but with sub-optimal supply of water

But the highest calorie output results are from third scenario which show 23.5% higher calorie outcome than the scenario which provides highest NER. To allocate land based on minimum fertilizer requirement with the consideration of only crops which directly fulfill food requirement, sesame and onion are the only crops which are occupying the land with the minimum fertilizer requirements. Moreover, for allocating the land based on minimum labor requirement, sesame, eggplant, tomato and onion are the crops which are allocated with the minimum labor requirement.

The overall finding of this study can be used to support the decision making and result demonstrate good guidelines for the planners; it can be helpful for farmer to take decision on adjustment of their cropping system according their demand (Max NER, Max Cal). Study shows that reduction in area of all crops and deficit irrigation are not the best options due to lower NER. Higher calorie is produced by keeping all crops with sub-optimal water supply, which obviously helps for food security. The study provides means for achieving higher NER, optimal irrigation supply for selective cropping system and less diversification with the limited water availability. Understanding of CWR, IWR, and the irrigation scheduling during the shortage months help farmers to take the right decision for preventing any yield reduction in their farm. And more finding would be applicable for other places in the country with similar climatic condition.

5.2 Recommendation

For making the study more effective the following should be taken in account,

- For better optimizing cropping system a study should focus on the other similar schemes with more detailed analysis of cropping systems with respect to farming style, different strategies to ascertain who use alternative sources (GW), who can reduce land and who extend the land, and explore farmers calorie demand from each crop.

- Though CROPWAT model provides reasonable estimates of CWR and IWR, for more reliable results it should be validated in context of study area

- The government's and NGO's subsidies for farmers to change their traditional irrigation system to more efficient system like drip and sprinkle irrigation, would improve the farmer NER and calories contribution.

- Water resource management aspect should be improved to alleviate losses to prevent water shortage in the study area.

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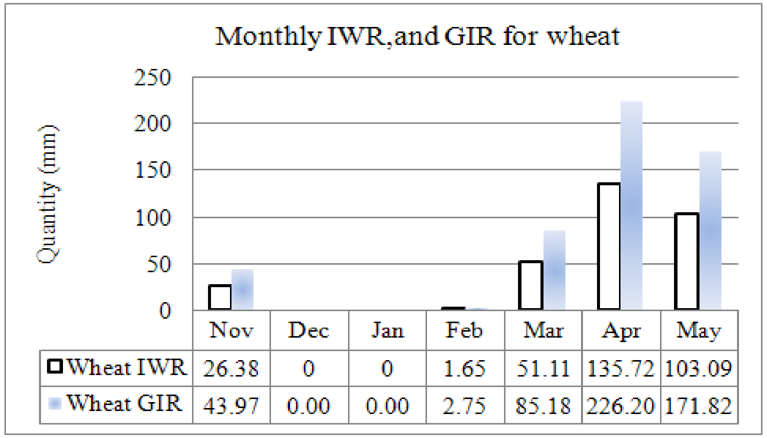
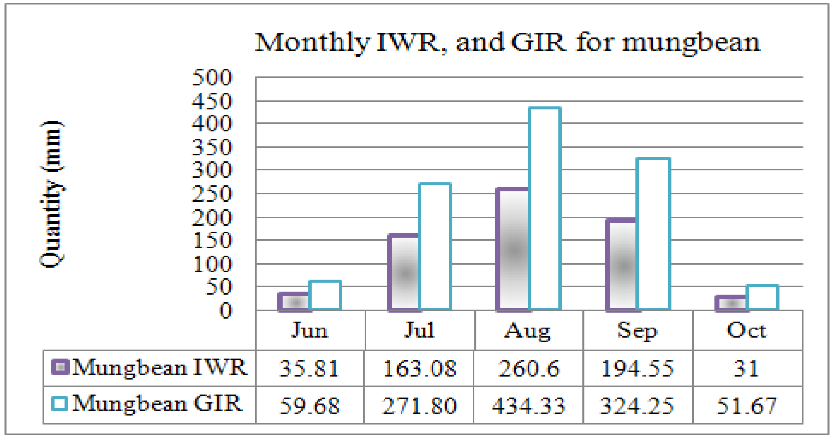
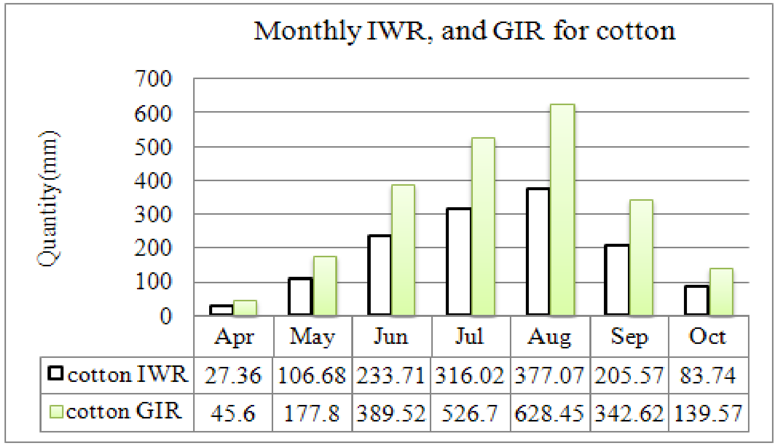
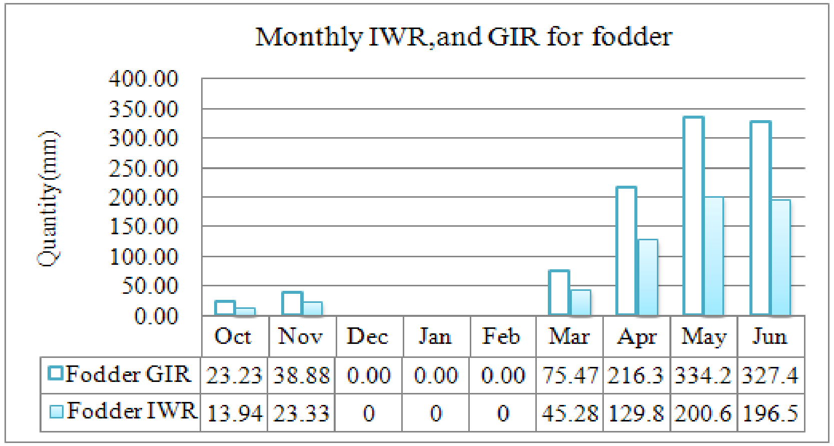
APPENDIX A

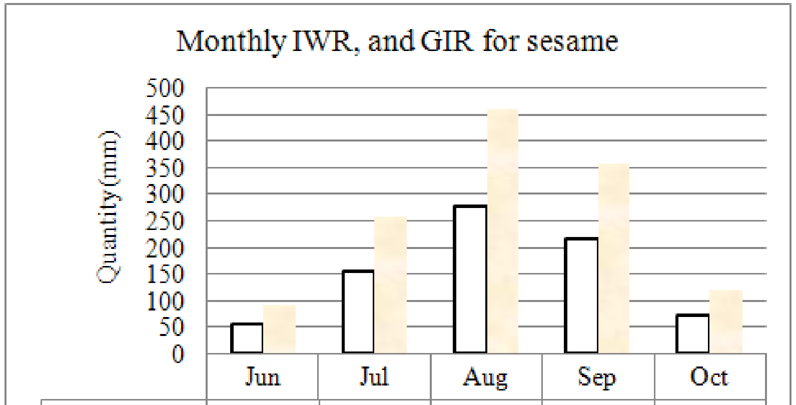
Monthly IWR and GIR for all crops are grown after May



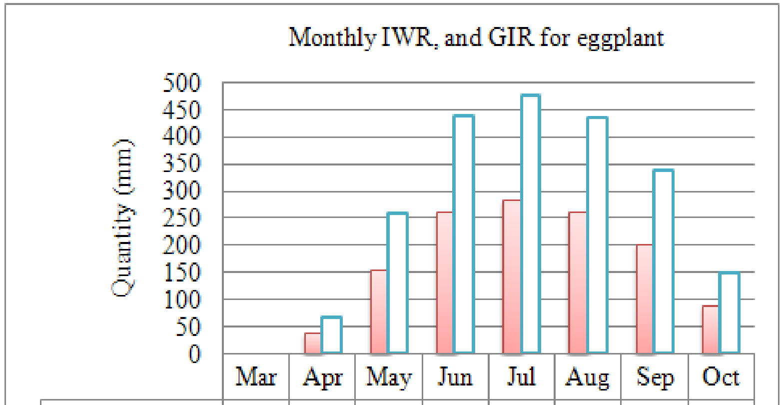




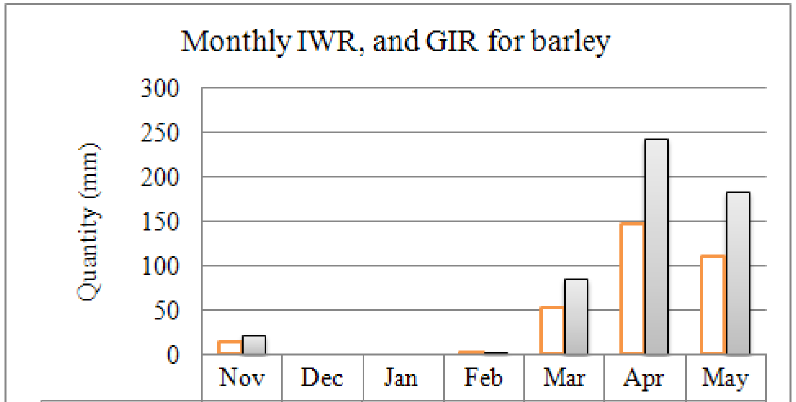




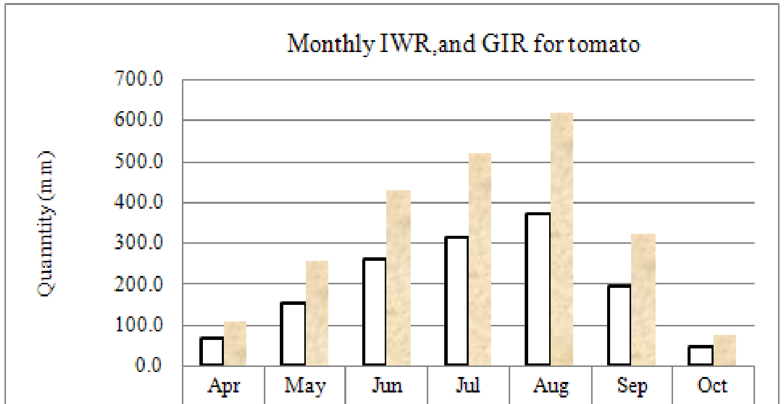
	Jun	Jul	Aug	Sep	Oct
sesame IWR	53.72	154.62	275.93	215.51	71.14
Sesame GIR	89.53	257.70	459.88	359.18	118.57



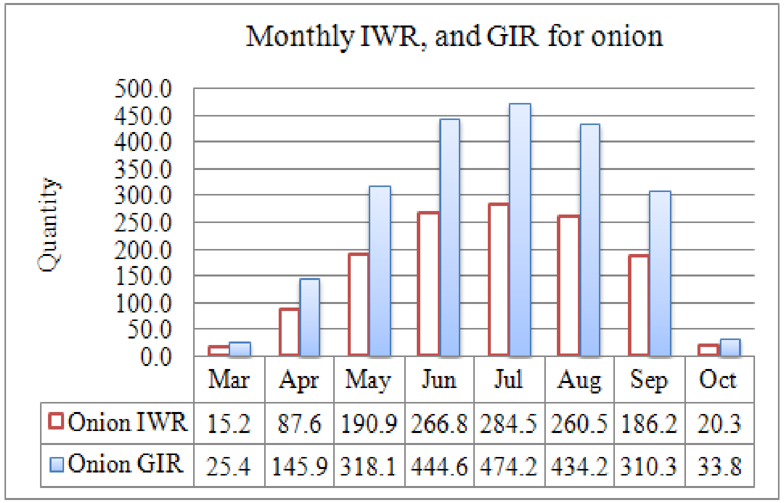
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Eggplant IWR	0	39.88	154.2	261.6	284.5	260.5	202.4	89.01
Eggplant GIR	0	66.47	257	436	474.2	434.2	337.4	148.4

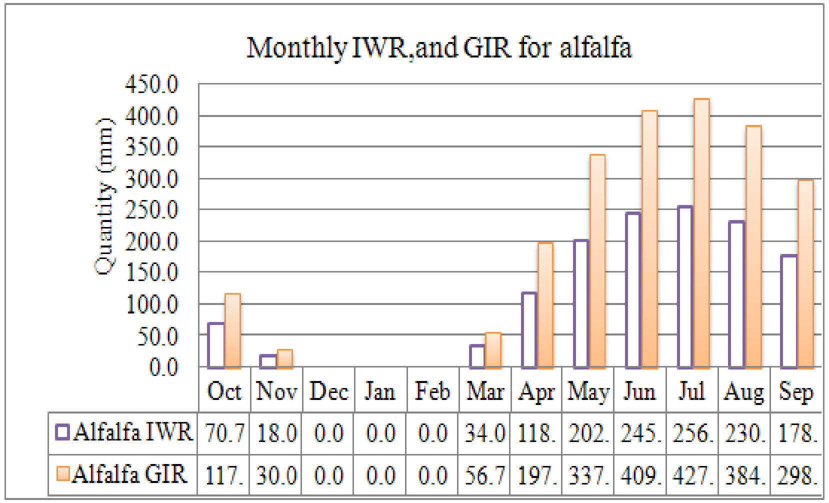


	Nov	Dec	Jan	Feb	Mar	Apr	May
Barley IWR	13.28	0	0	1.65	51.11	146.45	110.52
Barley GIR	22.13	0.00	0.00	2.75	85.18	244.08	184.20



	Apr	May	Jun	Jul	Aug	Sep	Oct
Tomato IWR	64.0	154.0	257.9	311.7	370.6	192.9	44.8
Tomato GIR	106.7	256.7	429.8	519.6	617.6	321.6	74.7

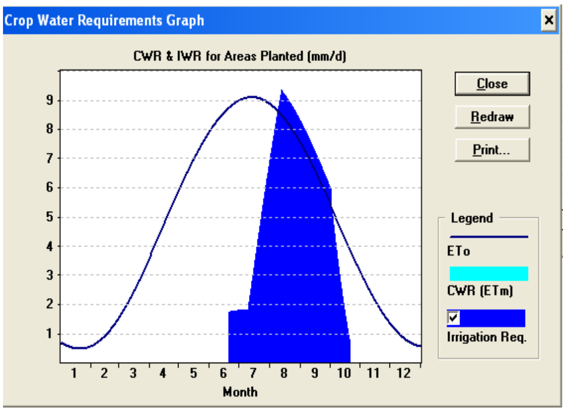

Monthly IWR, and GIR for onion
Quantity
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Mar Apr May Jun Jul Aug Sep Oct
Onion IWR 15.2 87.6 190.9 266.8 284.5 260.5 186.2 20.3
Onion GIR 25.4 145.9 318.1 444.6 474.2 434.2 310.3 33.8

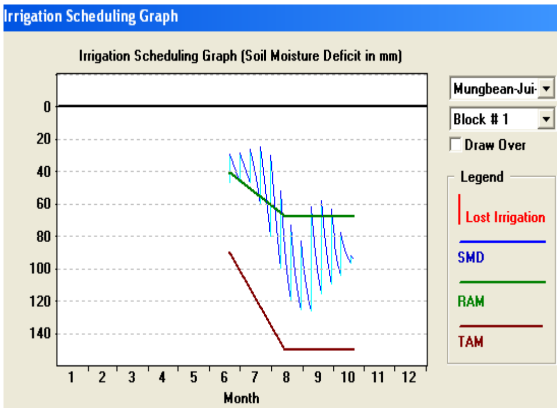

Monthly IWR,and GIR for alfalfa
Quantity (mm)
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Alfalfa IWR 70.7 18.0 0.0 0.0 0.0 34.0 118. 202. 245. 256. 230. 178.
Alfalfa GIR 117. 30.0 0.0 0.0 0.0 56.7 197. 337. 409. 427. 384. 298.

APPENDIX B

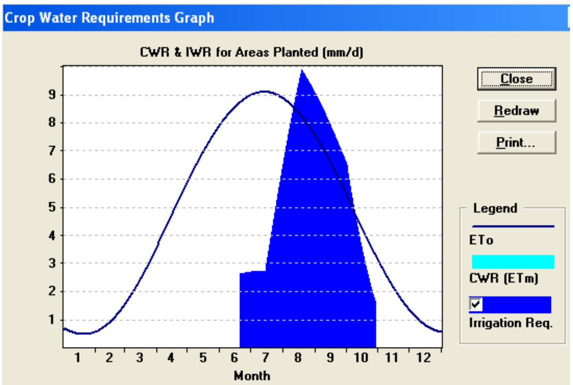
CWR, IWR, and Irrigation scheduling graphs for crops facing water scarcity

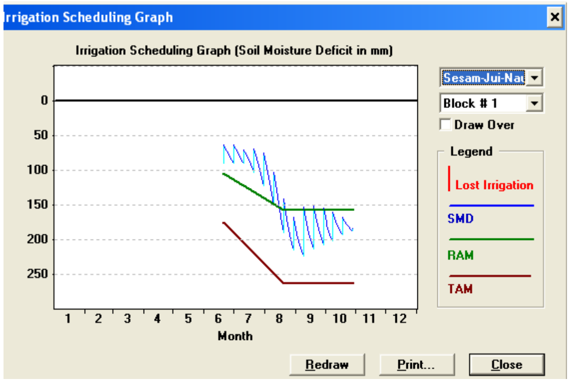
Mungbean



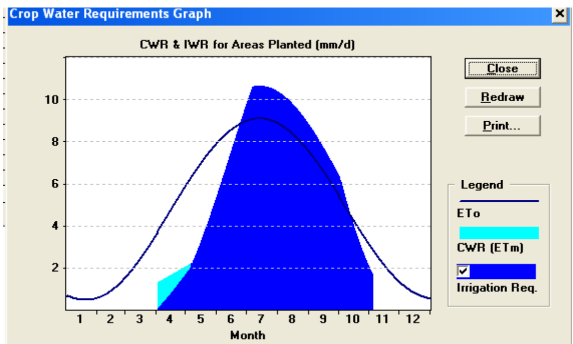


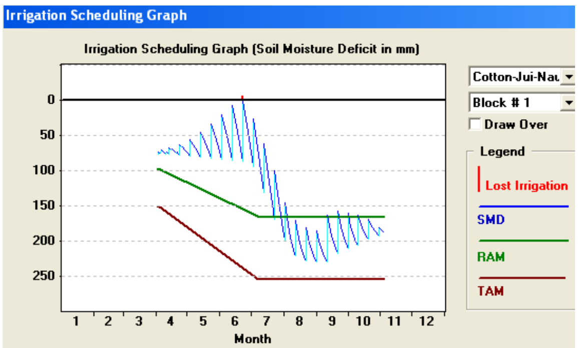
Sesame



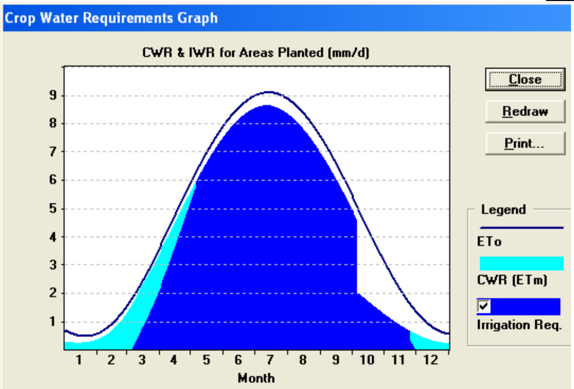


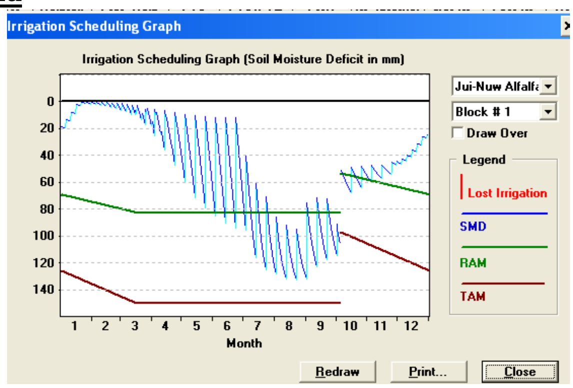
Cotton



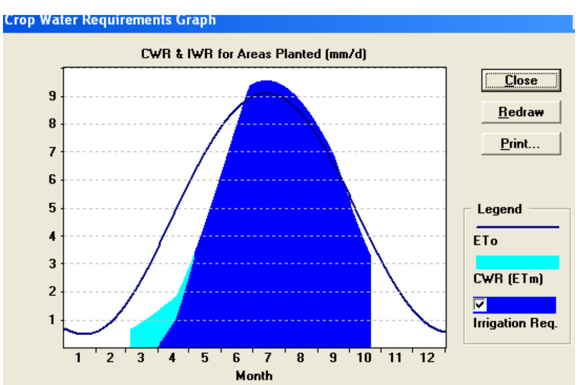


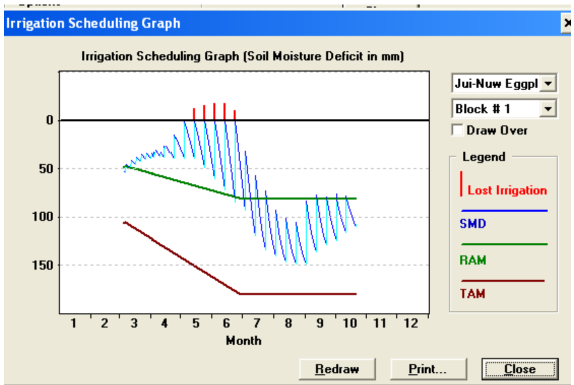
Alfalfa



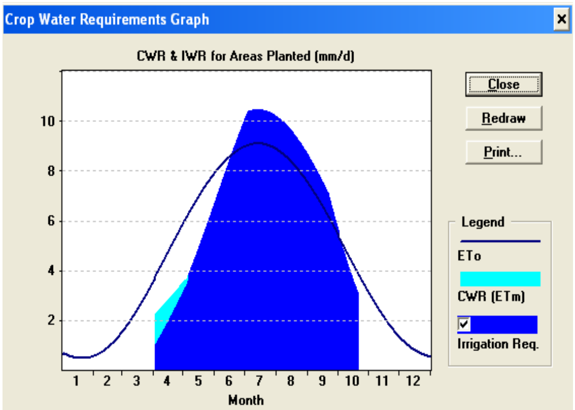


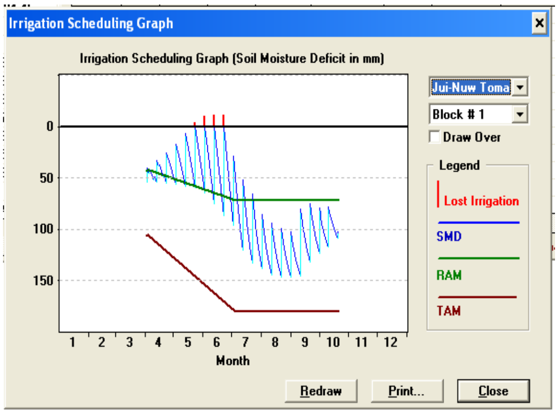
Eggplant



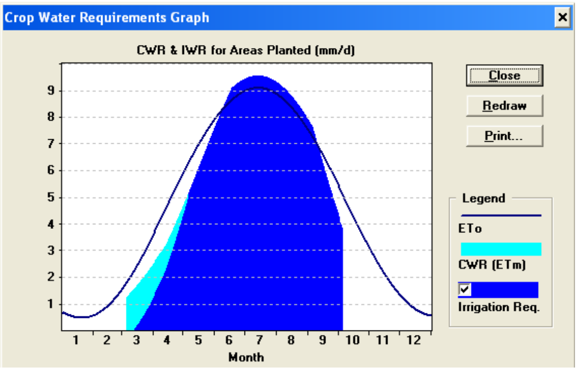


Tomato

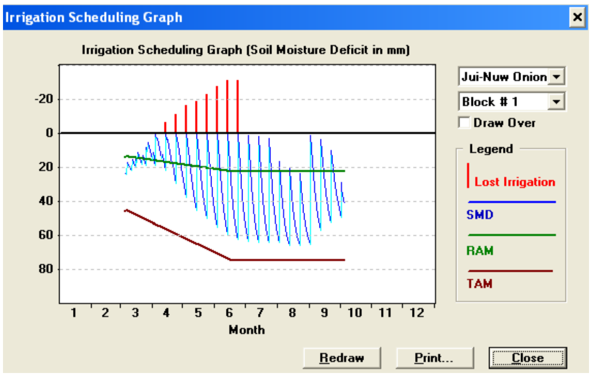




Onion



Crop Water Requirements Graph
CWR & IWR for Areas Planted (mm/d)
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12
Month
Close
Redraw
Print...
Legend
ETo
CWR (ETm)
Irrigation Req.



Irrigation Scheduling Graph
Irrigation Scheduling Graph (Soil Moisture Deficit in mm)
-20
0
20
40
60
80
1 2 3 4 5 6 7 8 9 10 11 12
Month
Jui-Nuw Onion
Block # 1
Draw Over
Legend
Lost Irrigation
SMD
RAM
TAM
Redraw
Print...
Close

APPENDIX C

Table C-1 Mean monthly wind speed in Herat – Afghanistan

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2008	NA	NA	NA	3	6	7	6	6	NA	NA	15	9
2007	5	NA	NA	5	6	6	6	11	11	18	16	13
2006	5	5	4	4	6	5	5	10	17	20	18	8
2005	5	5	4	4	6	5	5	10	17	20	18	8
2004	NA	NA	NA	NA	6	5	7	7	14	15	16	13
2003	14	7	4	5	7	8	5	8	12	16	18	11
2002	6	NA	5	5	8	7	6	7	10	16	18	10
Mean monthly wind Speed (2002-2008)	7	5	4	4	6	6	6	8	13	17	17	10

Table C-2 Mean monthly Sunshine in Herat – Afghanistan

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2008	NA	NA	NA	5:11	7:49	6:37	7:45	12:21	NA	NA	11:41	10:18
2007	9:27	NA	NA	6:42	6:03	6:10	7:57	11:50	11:16	12:00	11:59	10:58
2006	NA	6:30	NA	5:05	5:35	5:50	7:33	8:21	8:45	8:42	NA	NA
2005	8:53	7:16	6:40	6:49	5:44	6:05	8:11	10:24	10:47	10:46	10:10	9:34
2004	NA	NA	NA	NA	8:12	7:29	NA	NA	NA	12:03	12:11	7:40
2003	10:08	6:54	NA	5:11	6:44	7:01	8:51	11:35	11:18	11:37	11:52	NA
2002	NA	NA	NA	6:11	6:39	8:20	7:54	NA	NA	NA	NA	NA
2001	8:25	6:53	4:07	NA	NA	NA	NA	NA	NA	NA	NA	NA
Average Sunshine hours (2001-2008)	9:13	6:53	5:23	5:51	6:41	6:47	8:02	10:54	10:31	11:01	11:35	9:38

Table C-3 Mean monthly humidity in Herat – Afghanistan

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1942	30	52	66	74	64	60	55	35	27	22	24	26
1943	65	76	88	NA	71	72	59	60	NA	NA	NA	56
1944	45	58	61	87	91	80	73	65	46	43	34	37
1945	37	56	69	72	70	65	68	55	35	29	30	30
1946	38	53	59	64	62	60	60	44	30	22	26	30
1947	42	63	78	59	63	57	57	54	35	27	27	28
1948	57	61	70	78	73	59	62	47	53	NA	NA	46
1949	57	61	76	81	73	67	52	41	42	40	50	56
1951	49	49	46	66	75	50	55	36	34	33	38	38
1952	40	52	68	69	71	59	68	51	39	22	14	22
1955	44	62	84	57	61	54	49	50	34	30	29	30
1956	43	58	54	82	72	64	60	52	45	44	50	56
1958	41	45	56	70	55	70	63	46	44	41	22	28
1959	34	51	53	62	66	59	59	34	21	22	21	21
1960	39	48	74	79	67	71	50	44	37	29	32	32
1961	27	30	59	70	61	59	46	35	28	24	19	29
1962	32	45	69	78	80	64	57	37	27	29	26	35
1963	40	46	72	71	67	59	60	44	31	28	26	32
1964	48	51	71	83	73	67	62	50	30	27	26	33
1965	43	60	62	82	61	59	54	38	26	23	26	25
1966	32	67	60	68	65	54	44	38	27	23	20	21
1967	36	41	64	67	64	58	43	34	23	17	21	22
1968	31	79	60	73	79	63	53	42	35	28	34	35
1969	47	47	57	68	64	59	51	44	34	35	34	37
1970	47	74	76	71	73	74	51	39	31	31	36	33
1971	51	50	63	70	66	61	63	50	41	37	41	45
1972	39	56	73	70	62	58	47	40	32	21	26	34
1973	38	49	72	72	59	59	49	36	30	27	28	27
1974	35	40	46	47	56	51	47	39	32	28	21	22
1975	61	46	45	34	35	42	37	29	22	26	24	37
1976	41	NA	NA	64	61	59	55	64	55	38	40	43
2001	34.9	46.9	48.8	54.8	44.2	46.5	45.1	34.0	24.1	NA	NA	31.8
2002	51.8	53.7	75.9	64.2	66.3	52.7	57.4	51.6	35.1	NA	NA	40.0
2003	44.5	56.9	67.8	63.8	56.0	55.4	53.6	47.2	34.7	28.4	26.8	35.1
2004	NA	NA	63.8	NA	44.1	45.6	NA	NA	NA	37.1	31.8	37.7
2005	54.0	63.2	60.0	72.1	73.2	73.1	69.3	59.7	51.1	39.4	41.1	43.1
2006	49.1	60.0	67.8	71.7	61.5	58.8	54.3	48.9	33.3	33.5	28.8	39.7
2007	55.3	NA	NA	59.8	66.0	61.1	56.0	45.2	37.8	31.9	29.4	33.2
Average of (1942-1976)	42.2	54.2	65.0	69.6	66.5	61.1	55.1	44.3	34.2	29.2	29.1	33.7
Average of (19421-2007)	43.2	54.5	64.9	68.8	65.1	60.2	55.3	44.8	34.5	29.9	29.5	34.4

Table C-4 Mean monthly temperature in Herat-Afghanistan

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1942	17.4	12.3	3.5	5.6	4.9	12.2	15	23.3	29.6	26.7	27.2	23.1
1943	14.6	8.3	6.9	2.1	4.8	7.7	15.1	21	27.3	30.7	28.6	22.6
1944	15.3	10.3	10.3	5	6.6	13.5	16.8	25	28.4	33	29.7	23.5
1945	16.3	9.5	4.8	2.3	3.9	11.7	17.2	20.1	27.5	30.2	29.6	24.1
1946	17	4.9	2	2.4	8	11.7	19.1	25.3	27.9	29.9	28.5	24.3
1947	15.9	12.9	4.1	6.2	6.6	12.3	17.1	22.2	26.7	29.7	30.5	21.7
1948	14.5	8.2	1.6	6.6	8.7	10.4	15.8	24.3	24.9	30.7	28.7	24
1949	13.1	6.1	4.8	2.2	6.1	10	16.8	22.2	27	31.3	27.7	23.2
1951	20	8.2	3.8	3	9.8	8.5	14	21	20	29.8	28.2	22.5
1952	20	8.5	3	2.9	8.8	7.9	14	20.9	27.3	28.5	28	22.5
1955	14	10.6	7	5.5	7.7	10.8	14.1	26.4	29	28.9	29.5	23.1
1956	17.9	10.6	7	3.1	6.1	8.7	16.6	22.2	23.5	30.3	27.5	23.9
1958	15.2	3.7	6.2	5.5	6	12.5	11.1	20.7	27.1	29.3	26.6	22.1
1959	16.1	7.1	0.2	2.5	3	9.9	18.7	21.2	26.8	28.7	29.3	24.8
1960	20.7	7.7	2.1	2.9	7.7	6.5	13.2	19.7	27.1	28.9	27.9	22.4
1961	14.8	8.7	6.7	3.3	3.9	10.8	14.1	23.3	26.7	30.3	27.5	23
1962	14.7	6.5	5	2.9	8.6	12.4	15.7	22	25.6	30.1	26.4	20.3
1963	17.5	8.9	2.3	6.4	9.5	10.7	18.2	20.8	27.7	29.2	27.1	22.6
1964	11.5	7.9	-0.3	-6.7	4.9	12.8	15.4	21.6	26.7	29.5	28.1	22.1
1965	11.7	11.9	3.5	11.5	5.4	9.4	15.3	22.4	26.6	29.8	27	23
1966	14.5	5.7	4.6	7.1	8.2	10.4	14.8	20.8	28.9	29.1	27.6	22
1967	14.9	10.4	4.5	-0.1	3.5	9.1	13.6	19.6	25.2	29.3	27.7	22.9
1968	15.8	10.1	5.7	3.7	3.7	10.3	14.6	19.6	26.5	28.6	27.3	22.1
1969	16.2	6.6	6.8	-0.6	1.7	13.4	15.4	20.2	26	28.4	26.4	21.2
1970	15.4	10.3	5.1	3.1	6.8	9	17	23.4	27	28.4	29.7	21.8
1971	16.1	12.4	8.3	0.1	6.8	12.2	17	24.5	28.6	29.4	27.7	22.1
1972	16.1	11.3	0.7	-0.7	-4.4	7.8	16.6	20.3	26.6	27.7	24.7	22.2
1973	16.3	9.1	3.4	-1.7	8.8	9.8	18.5	22.4	29.3	30.4	29	21.7
1974	12.8	8.6	3.4	0.2	0	10.2	16	21.7	27.2	29.6	26.5	22.2
1975	14.1	6.6	3.8	2.4	4.4	9.9	14.8	22	27.5	30.5	28.4	23.1
1976	16	4.9	3.7	5.7	3.2	6.8	15.4	22.1	26.7	30.5	28.6	23.4
1977	16.7	10.9	6.3	-2.6	5.4	14.4	17	23.1	30	30.6	27.9	22.5
1978	16.7	6.9	8.8	2.7	5.1	9.6	18.2	22.8	27.7	29.8	27.7	23.5
1979	19.2	8.1	6.1	3.9	6.5	7.9	21	20.2	27.7	31.1	27.6	23.3
1980	16.9	12.1	7.1	2.7	2.1	10.8	19.7	23.6	27.8	30.5	28.3	22.9
1981	15.2	10.4	7.9	5.4	7.1	13	17.9	23.1	27.1	29.9	28.2	23
1982	17.8	7.3	3	4.6	3.7	8.3	17.5	23.1	27.9	30	28	22.1
1983	14.9	11.8	4.1	3.1	6.5	8.1	14.7	22.9	29.2	32.2	30.6	29.3
1984	14.6	11.8	0.8	2.9	0	12.9	17.4	23	27.8	31.5	30.9	21.6
1985	15.3	10.4	5.8	7.2	8.9	8.7	18	23.4	29.1	31.2	26.9	22.7
1986	15.7	11.1	7.2	3.1	5.1	5.8	15.7	22.9	27.7	29.1	27	23.4
1987	12.7	9.7	5.2	5.5	6.8	12.4	15.9	21.1	24.9	26.6	29.9	23.3
1988	15.2	10.3	5.3	3.9	5.7	9.6	16.5	21.8	28.2	31.1	26.6	22.1

cont. …

Table C-4 Mean monthly temperature in Herat-Afghanistan

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2000	17.0	9.0	7.5	5.9	5.8	10.5	20.3	25.5	26.0	27.5	28.0	24.5
2001	18.0	13.5	9.1	3.0	6.0	12.5	20.5	26.0	27.5	28.5	27.5	23.0
2002	20.1	12.5	9.1	6.1	7.3	13.1	17.0	22.5	29.0	28.0	28.2	23.9
2003	17.2	15.0	-2.3	6.3	7.9	10.9	16.6	20.1	24.7	30.2	28.1	24.6
2004	17.0	7.5	7.4	5.8	9.5	12.5	15.0	21.5	28.0	29.0	28.5	23.5
2005	17.1	10.1	6.7	4.2	4.8	12.4	16.3	18.8	25.8	31.1	35.0	24.7
2006	20.6	12.2	4.3	1.7	10.9	13.0	17.9	26.3	28.8	29.7	29.2	21.4
2007	13.6	NA	NA	5.1	7.8	10.1	19.5	22.0	27.5	29.4	28.1	22.8
Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Temp (1942 to 2007)	17.56	11.4	6.0	4.8	7.5	11.9	17.9	22.8	27.2	29.2	29.1	23.6
Mean Temp (2000 to 2007)	17.6	11.4	6.0	4.8	7.5	11.9	17.9	22.8	27.2	29.2	29.1	23.6
Mean Min	13.56	7.5	-2.3	1.73	4.8	10.08	15	18.8	24.65	27.5	27.5	21.4
Mean Max	20.75	15	10.3	6.6	10.9	14.4	21	26.4	30	33	35	35

Table C-5 Mean monthly precipitation in Herat – Afghanistan

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1941-2	NA	NA	NA	93.4	44.9	59.2	25.0	4.4	0.0	0.0	0.0	0.0
1942-3	0.8	21.9	54.7	56.2	30.2	61.9	1.3	0.0	0.0	0.0	0.0	0.0
1943-4	0.0	10.7	31.6	50.0	28.3	19.4	12.4	0.0	0.0	0.0	0.0	0.0
1944-5	0.0	1.0	61.5	71.0	20.2	33.0	6.1	24.5	0.0	0.0	0.0	0.0
1945-6	0.0	8.0	43.2	54.5	29.0	19.3	1.1	0.0	0.0	0.0	0.0	0.0
1946-7	0.0	21.4	21.4	50.2	66.5	59.9	1.0	1.1	0.0	0.0	0.0	0.0
1947-8	0.0	1.6	13.5	51.1	14.1	17.9	29.6	0.1	0.0	0.0	0.0	0.0
1948-9	0.0	9.3	31.2	45.9	27.2	101.8	18.9	0.2	0.0	0.0	0.0	0.0
1949-50	0.0	0.0	20.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
1950-1	NA	NA	NA	37.2	9.9	96.8	5.3	0.0	0.0	0.0	0.0	0.0
1951-2	0.0	0.0	15.8	86.2	49.5	45.5	12.9	3.2	0.0	0.0	0.0	0.0
1952-3	NA	NA	29.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
1953-4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1954-5	NA	NA	0.0	22.7	NA	88.9	75.7	10.6	0.0	0.0	0.0	0.0
1955-6	0.0	0.0	44.1	41.3	29.9	119.8	17.1	0.0	0.0	0.0	0.0	0.0
1956-7	0	0	33.4	NA	NA	NA	NA	0.0	NA	NA	NA	NA
1957-8	0	0	0.0	38.5	11.0	8.5	19.2	0.0	0.0	0.0	0.0	1.2
1958-9	0	0	36.2	35.4	26.0	51.9	6.9	10.2	1.5	0.0	0.0	0.0
1959-60	0.0	23.9	78.1	3.5	64.6	59.1	64.1	6.8	0.0	0.0	0.0	0.0
1960-1	0.0	0.4	0.0	20.9	8.0	88.4	75.7	4.4	0.0	0.0	0.0	0.0
1961-2	0.0	39.4	51.7	5.0	20.7	31.2	29.0	5.0	0.0	0.0	0.0	0.0
1962-3	0.0	7.2	15.8	12.7	14.4	20.7	40.5	91.2	0.0	0.0	0.0	0.0
1963-4	0.0	3.7	30.1	23.3	95.7	62.5	37.5	0.4	0.0	0.0	0.0	0.0
1964-5	0.0	14.4	3.2	117.5	24.7	6.5	16.4	5.4	0.0	0.0	0.0	0.0
1965-6	0.0	7.8	13.8	21.6	73.8	27.6	10.8	0.0	0.0	0.0	0.0	0.0
1966-7	13.8	0.0	5.5	33.7	75.5	39.9	90.1	1.1	0.0	0.0	0.0	0.0
1967-8	7.1	0.9	39.4	26.8	53.7	31.8	40.0	6.1	0.0	0.0	0.0	0.0
1968-9	0.0	11.9	126.1	70.2	42.3	27.5	65.8	7.0	0.0	0.0	0.0	0.0
1969-70	10.9	22.1	12.5	24.0	8.0	73.3	5.0	0.0	0.0	0.0	0.0	0.0
1970-1	0.0	0.0	1.0	3.6	41.0	43.5	19.6	0.0	0.0	0.0	0.0	0.0
1971-2	0.0	21.4	20.1	102.8	53.1	152.2	22.3	9.7	0.0	0.0	0.0	0.0
1972-3	0.0	13.0	53.3	49.9	30.4	37.5	3.2	0.0	0.0	0.0	0.0	0.0
1973-4	0.0	0.0	20.8	115.1	52.6	44.9	35.6	1.1	0.0	0.0	0.0	0.0
1974-5	0.0	0.0	101.7	54.4	77.1	71.3	77.1	7.1	0.0	0.0	0.0	0.0
1975-6	1.2	22.0	23.1	49.8	107.1	110.9	85.1	12.1	0.0	0.0	0.0	0.0
1976-7	1.2	0.0	32.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977-8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978-9	NA	NA	0.0	41.5	27.1	11.5	9.4	0.0	0.0	0.0	0.0	0.0
1979-80	3.5	2.7	82.2	81.1	138.2	98.2	22.4	0.0	0.0	0.0	0.0	0.0
1980-1	2.2	7.5	35.9	90.5	80.0	30.4	37.0	11.9	0.0	0.0	0.0	0.0
1981-2	17.0	2.6	30.2	60.0	121.4	175.1	2.5	86.2	0.0	0.0	0.0	0.0
1982-3	2.0	73.6	54.1	62.7	34.4	35.1	47.7	0.0	0.0	0.0	0.0	0.0
1983-4	0.0	0.0	31.8	38.1	13.5	40.7	9.8	1.0	0.0	0.0	0.0	0.0
1984-5	1.1	13.1	23.3	33.9	8.5	23.1	16.0	0.0	0.0	0.0	0.0	0.0
1985-6	0.6	2.0	30.9	15.0	90.7	99.5	24.5	0.0	0.0	0.0	0.0	0.0
1986-7	0.0	18.0	21.0	50.5	21.5	127.0	7.0	1.0	0.0	0.0	0.0	0.0
1987-8	1.6	0.0	NA	74.5	63.4	124.5	23.8	0.0	1.0	0.0	0.0	0.0
1988-9	0.0	NA	0.0	NA	NA	NA	NA	NA	NA	NA	NA	NA

cont. …

Table C-5 Mean monthly precipitation in Herat – Afghanistan

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2001-2	0.0	3.0	47.0	103.0	15.0	15.0	76.0	0.0	0.0	0.0	0.0	0.0
2002-3	0.0	7.0	36.0	36.0	61.0	49.0	41.0	0.0	0.0	0.0	0.0	0.0
2003-4	0.0	24.0	4.3	75.0	29.5	0.0	12.5	0.6	0.0	0.0	0.0	0.0
2004-5	0.0	10.0	166.3	5.0	25.2	25.2	0.0	NA	0.0	0.0	0.0	NA
2005-6	0.0	16.7	1.5	11.8	56.1	62.0	2.0	15.5	0.0	0.0	0.0	0.0
2006-7	0.0	69.5	32.5	66.5	20.0	7.1	13.5	0.0	0.0	0.0	0.0	0.0
2007-8	0.0	0.0	NA	17.0	43.8	78.5	11.5	0.0	0.0	0.0	0.0	0.0
2008-9	0.0	NA	NA	21.1	10.0	0.0	46.9	0.0	0.0	0.0	0.0	0.0
Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average of 1942-2008	1.26	10.708	33.226	47.012	41.746	54.29	27.076	6.558	0.05	0	0	0.024
Average of 2001-2008	0	16.275	35.95	41.925	32.575	29.6	25.425	2.0125	0	0	0	0

APPENDIX D

Table D-1 Crop water requirement report for wheat

- Crop # 1 : Jui-Nuw Wheat
- Block # : [All blocks]
- Planting date : 5/11
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
5/11	25.16	100.00	0.55	13.84	0.00	0.00	13.84	0.27
15/11	19.10	100.00	0.55	10.51	0.00	0.00	10.51	0.20
25/11	13.99	100.00	0.55	7.70	5.49	5.31	2.39	0.05
5/12	9.99	100.00	0.55	5.49	9.10	8.66	0.00	0.00
15/12	7.19	100.00	0.61	4.36	11.76	11.07	0.00	0.00
25/12	6.06	100.00	0.72	4.35	13.15	12.30	0.00	0.00
4/1	5.62	100.00	0.82	4.62	13.13	12.30	0.00	0.00
14/1	4.85	100.00	0.93	4.51	14.01	13.09	0.00	0.00
24/1	5.39	100.00	1.04	5.60	14.97	13.93	0.00	0.00
3/2	7.29	100.00	1.13	8.28	15.89	14.72	0.00	0.00
13/2	10.54	100.00	1.15	12.12	16.63	15.34	0.00	0.00
23/2	15.03	100.00	1.15	17.29	17.01	15.64	1.65	0.03
5/3	20.62	100.00	1.15	23.72	16.83	15.45	8.26	0.16
15/3	27.12	100.00	1.15	31.19	15.92	14.65	16.54	0.32
25/3	34.29	100.00	1.15	39.43	14.16	13.12	26.31	0.51
4/4	41.89	100.00	1.15	48.17	11.54	10.82	37.35	0.72
14/4	49.67	100.00	1.13	56.03	8.17	7.83	48.20	0.93
24/4	57.36	100.00	0.95	54.53	4.42	4.36	50.17	0.97
4/5	64.73	100.00	0.75	48.12	0.44	0.44	47.69	0.92
14/5	71.53	100.00	0.54	38.36	0.00	0.00	38.36	0.74
24/5	45.87	100.00	0.37	17.04	0.00	0.00	17.04	0.55
Total	543.30			455.25	202.62	189.03	318.32	[0.30]

Table D-2 Crop water requirement report for mungbean

```
- Crop  # 1                 : Mungbean-Jui-Nuw
- Block #                   : [All blocks]
- Planting date             : 20/6
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				----------	(mm/period)	----------		
20/6	88.62	100.00	0.20	17.72	0.00	0.00	17.72	0.34
30/6	90.43	100.00	0.20	18.09	0.00	0.00	18.09	0.35
10/7	90.90	100.00	0.35	31.41	0.00	0.00	31.41	0.61
20/7	90.02	100.00	0.61	54.90	0.00	0.00	54.90	1.06
30/7	87.81	100.00	0.88	76.77	0.00	0.00	76.77	1.48
9/8	84.34	100.00	1.08	91.41	0.00	0.00	91.41	1.76
19/8	79.72	100.00	1.10	87.69	0.00	0.00	87.69	1.69
29/8	74.09	100.00	1.10	81.50	0.00	0.00	81.50	1.57
8/9	67.64	100.00	1.10	74.40	0.00	0.00	74.40	1.44
18/9	60.55	100.00	1.10	66.60	0.00	0.00	66.60	1.28
28/9	53.05	100.00	1.01	53.55	0.00	0.00	53.55	1.03
8/10	45.39	100.00	0.58	26.72	0.00	0.00	26.72	0.52
18/10	16.02	100.00	0.27	4.30	0.00	0.00	4.30	0.21
Total	928.58			685.07	0.00	0.00	685.07	[1.07]

```
* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
********************************************************************************
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Table D-3 Crop water requirement report for sesame

- Crop # 1 : Sesam-Jui-Nau
- Block # : [All blocks]
- Planting date : 20/6
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				---------- (mm/period) ----------				
20/6	88.62	100.00	0.30	26.59	0.00	0.00	26.59	0.51
30/6	90.43	100.00	0.30	27.13	0.00	0.00	27.13	0.52
10/7	90.90	100.00	0.34	30.77	0.00	0.00	30.77	0.59
20/7	90.02	100.00	0.57	51.28	0.00	0.00	51.28	0.99
30/7	87.81	100.00	0.83	72.57	0.00	0.00	72.57	1.40
9/8	84.34	100.00	1.08	91.36	0.00	0.00	91.36	1.76
19/8	79.72	100.00	1.20	95.66	0.00	0.00	95.66	1.85
29/8	74.09	100.00	1.20	88.91	0.00	0.00	88.91	1.72
8/9	67.64	100.00	1.20	81.16	0.00	0.00	81.16	1.57
18/9	60.55	100.00	1.20	72.66	0.00	0.00	72.66	1.40
28/9	53.05	100.00	1.16	61.69	0.00	0.00	61.69	1.19
8/10	45.39	100.00	0.93	42.27	0.00	0.00	42.27	0.82
18/10	37.81	100.00	0.67	25.44	0.00	0.00	25.44	0.49
28/10	6.68	100.00	0.51	3.43	0.00	0.00	3.43	0.33
Total	957.04			770.92	0.00	0.00	770.92	[1.13]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-4 Crop water requirement report for cotton

- Crop # 1 : Cotton-Jui-Nau
- Block # : [All blocks]
- Planting date : 3/4
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
3/4	41.12	100.00	0.35	14.39	11.83	11.09	3.31	0.06
13/4	48.89	100.00	0.35	17.11	8.53	8.16	8.95	0.17
23/4	56.60	100.00	0.35	19.81	4.80	4.72	15.10	0.29
3/5	64.01	100.00	0.37	23.76	0.71	0.71	23.05	0.44
13/5	70.88	100.00	0.49	35.05	0.00	0.00	35.05	0.68
23/5	77.00	100.00	0.63	48.58	0.00	0.00	48.58	0.94
2/6	82.17	100.00	0.77	63.06	0.00	0.00	63.06	1.22
12/6	86.24	100.00	0.90	77.96	0.00	0.00	77.96	1.50
22/6	89.09	100.00	1.04	92.69	0.00	0.00	92.69	1.79
2/7	90.64	100.00	1.16	104.81	0.00	0.00	104.81	2.02
12/7	90.83	100.00	1.17	106.28	0.00	0.00	106.28	2.05
22/7	89.68	100.00	1.17	104.93	0.00	0.00	104.93	2.02
1/8	87.21	100.00	1.17	102.04	0.00	0.00	102.04	1.97
11/8	83.50	100.00	1.17	97.70	0.00	0.00	97.70	1.88
21/8	78.67	100.00	1.17	92.04	0.00	0.00	92.04	1.78
31/8	72.86	100.00	1.17	85.25	0.00	0.00	85.25	1.64
10/9	66.26	100.00	1.17	77.53	0.00	0.00	77.53	1.50
20/9	59.07	100.00	1.17	69.11	0.00	0.00	69.11	1.33
30/9	51.52	100.00	1.14	58.93	0.00	0.00	58.93	1.14
10/10	43.86	100.00	0.98	42.96	0.00	0.00	42.96	0.83
20/10	36.32	100.00	0.79	28.92	0.00	0.00	28.92	0.56
30/10	18.33	100.00	0.65	11.86	0.00	0.00	11.86	0.38
Total	1484.76			1374.78	25.88	24.67	1350.11	[1.21]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-5 Crop water requirement report for barley

- Crop # 1 : Jui-Nuw Barley
- Block # : [All blocks]
- Planting date : 5/11
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				---------- (mm/period) ----------				
5/11	25.16	100.00	0.30	7.55	0.00	0.00	7.55	0.15
15/11	19.10	100.00	0.30	5.73	0.00	0.00	5.73	0.11
25/11	13.99	100.00	0.30	4.20	5.49	5.31	0.00	0.00
5/12	9.99	100.00	0.38	3.79	9.10	8.66	0.00	0.00
15/12	7.19	100.00	0.54	3.82	11.76	11.07	0.00	0.00
25/12	6.06	100.00	0.69	4.17	13.15	12.30	0.00	0.00
4/1	5.62	100.00	0.84	4.70	13.13	12.30	0.00	0.00
14/1	4.85	100.00	0.99	4.80	14.01	13.09	0.00	0.00
24/1	5.39	100.00	1.13	6.08	14.97	13.93	0.00	0.00
3/2	7.29	100.00	1.15	8.38	15.89	14.72	0.00	0.00
13/2	10.54	100.00	1.15	12.12	16.63	15.34	0.00	0.00
23/2	15.03	100.00	1.15	17.29	17.01	15.64	1.65	0.03
5/3	20.62	100.00	1.15	23.72	16.83	15.45	8.26	0.16
15/3	27.12	100.00	1.15	31.19	15.92	14.65	16.54	0.32
25/3	34.29	100.00	1.15	39.43	14.16	13.12	26.31	0.51
4/4	41.89	100.00	1.15	48.17	11.54	10.82	37.35	0.72
14/4	49.67	100.00	1.15	57.12	8.17	7.83	49.29	0.95
24/4	57.36	100.00	1.12	64.17	4.42	4.36	59.81	1.15
4/5	64.73	100.00	0.86	55.81	0.44	0.44	55.38	1.07
14/5	71.53	100.00	0.56	40.26	0.00	0.00	40.26	0.78
24/5	45.87	100.00	0.33	14.88	0.00	0.00	14.88	0.48
Total	543.30			457.37	202.62	189.03	323.01	[0.30]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-6 Crop water requirement report for fodder

- Crop # 1 : Jui-Nuw Clover
- Block # : [All blocks]
- Planting date : 22/10
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				---------- (mm/period) ----------				
22/10	34.86	100.00	0.40	13.94	0.00	0.00	13.94	0.27
1/11	27.81	100.00	0.40	11.12	0.00	0.00	11.12	0.21
11/11	21.42	100.00	0.40	8.57	0.00	0.00	8.57	0.17
21/11	15.91	100.00	0.40	6.36	2.80	2.72	3.64	0.07
1/12	11.45	100.00	0.40	4.58	7.78	7.44	0.00	0.00
11/12	8.16	100.00	0.45	3.62	10.80	10.21	0.00	0.00
21/12	6.12	100.00	0.53	3.23	12.95	12.13	0.00	0.00
31/12	6.10	100.00	0.61	3.73	12.95	12.13	0.00	0.00
10/1	5.01	100.00	0.70	3.48	13.64	12.76	0.00	0.00
20/1	5.01	100.00	0.78	3.91	14.58	13.60	0.00	0.00
30/1	6.36	100.00	0.86	5.50	15.53	14.42	0.00	0.00
9/2	9.08	100.00	0.90	8.17	16.37	15.12	0.00	0.00
19/2	13.09	100.00	0.90	11.78	16.92	15.57	0.00	0.00
1/3	18.27	100.00	0.90	16.44	16.98	15.59	0.85	0.02
11/3	24.43	100.00	0.90	21.98	16.38	15.05	6.93	0.13
21/3	31.36	100.00	0.90	28.22	14.97	13.82	14.40	0.28
31/3	38.81	100.00	0.90	34.93	12.69	11.83	23.10	0.45
10/4	46.55	100.00	0.90	41.90	9.59	9.10	32.80	0.63
20/4	54.31	100.00	0.90	48.88	5.93	5.78	43.10	0.83
30/4	61.84	100.00	0.90	55.65	1.76	1.75	53.91	1.04
10/5	68.89	100.00	0.90	62.00	0.00	0.00	62.00	1.20
20/5	75.25	100.00	0.89	67.27	0.00	0.00	67.27	1.30
30/5	80.72	100.00	0.88	71.29	0.00	0.00	71.29	1.38
9/6	85.14	100.00	0.87	74.26	0.00	0.00	74.26	1.43
19/6	88.37	100.00	0.86	76.12	0.00	0.00	76.12	1.47
29/6	54.04	100.00	0.85	46.08	0.00	0.00	46.08	1.48
Total	898.36			733.04	202.62	189.03	609.38	[0.46]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-7 Crop water requirement report for alfalfa

```
*******************************************************************************

- Crop  # 1              : Jui-Nuw Alfalfa
- Block #                : [All blocks]
- Planting date          : 6/10
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				----------	(mm/period)		----------	
6/10	46.92	100.00	0.40	18.77	0.00	0.00	18.77	0.36
16/10	39.31	100.00	0.40	15.72	0.00	0.00	15.72	0.30
26/10	31.97	100.00	0.40	12.79	0.00	0.00	12.79	0.25
5/11	25.16	100.00	0.40	10.06	0.00	0.00	10.06	0.19
15/11	19.10	100.00	0.40	7.64	0.00	0.00	7.64	0.15
25/11	13.99	100.00	0.40	5.60	5.49	5.31	0.29	0.01
5/12	9.99	100.00	0.40	3.99	9.10	8.66	0.00	0.00
15/12	7.19	100.00	0.40	2.88	11.76	11.07	0.00	0.00
25/12	6.06	100.00	0.40	2.42	13.15	12.30	0.00	0.00
4/1	5.62	100.00	0.44	2.48	13.13	12.30	0.00	0.00
14/1	4.85	100.00	0.52	2.53	14.01	13.09	0.00	0.00
24/1	5.39	100.00	0.60	3.24	14.97	13.93	0.00	0.00
3/2	7.29	100.00	0.68	4.97	15.89	14.72	0.00	0.00
13/2	10.54	100.00	0.76	8.01	16.63	15.34	0.00	0.00
23/2	15.03	100.00	0.84	12.60	17.01	15.64	0.00	0.00
5/3	20.62	100.00	0.91	18.90	16.83	15.45	3.45	0.07
15/3	27.12	100.00	0.95	25.76	15.92	14.65	11.11	0.21
25/3	34.29	100.00	0.95	32.57	14.16	13.12	19.46	0.38
4/4	41.89	100.00	0.95	39.80	11.54	10.82	28.97	0.56
14/4	49.67	100.00	0.95	47.18	8.17	7.83	39.35	0.76
24/4	57.36	100.00	0.95	54.49	4.42	4.36	50.14	0.97
4/5	64.73	100.00	0.95	61.49	0.44	0.44	61.05	1.18
14/5	71.53	100.00	0.95	67.95	0.00	0.00	67.95	1.31
24/5	77.56	100.00	0.95	73.68	0.00	0.00	73.68	1.42
3/6	82.63	100.00	0.95	78.49	0.00	0.00	78.49	1.51
13/6	86.58	100.00	0.95	82.25	0.00	0.00	82.25	1.59
23/6	89.30	100.00	0.95	84.84	0.00	0.00	84.84	1.64
3/7	90.72	100.00	0.95	86.18	0.00	0.00	86.18	1.66
13/7	90.78	100.00	0.95	85.95	0.00	0.00	85.95	1.66
23/7	89.49	100.00	0.94	84.20	0.00	0.00	84.20	1.62
2/8	86.89	100.00	0.93	81.25	0.00	0.00	81.25	1.57
12/8	83.07	100.00	0.93	77.18	0.00	0.00	77.18	1.49
22/8	78.13	100.00	0.92	72.14	0.00	0.00	72.14	1.39
1/9	72.24	100.00	0.92	66.27	0.00	0.00	66.27	1.28
11/9	65.56	100.00	0.91	59.76	0.00	0.00	59.76	1.15
21/9	58.33	100.00	0.91	52.83	0.00	0.00	52.83	1.02
1/10	26.34	100.00	0.90	23.73	0.00	0.00	23.73	0.92
Total	1693.25			1470.62	202.62	189.03	1355.53	[0.72]

Table D-8 Crop water requirement report for eggplant

Crop Water Requirements Report

- Crop # 1 : Jui-Nuw Eggplant
- Block # : [All blocks]
- Planting date : 5/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
5/3	20.62	100.00	0.37	7.63	16.83	15.45	0.00	0.00
15/3	27.12	100.00	0.37	10.03	15.92	14.65	0.00	0.00
25/3	34.29	100.00	0.37	12.69	14.16	13.12	0.00	0.00
4/4	41.89	100.00	0.37	15.50	11.54	10.82	4.68	0.09
14/4	49.67	100.00	0.38	19.14	8.17	7.83	11.31	0.22
24/4	57.36	100.00	0.47	27.14	4.42	4.36	22.78	0.44
4/5	64.73	100.00	0.57	36.90	0.44	0.44	36.46	0.70
14/5	71.53	100.00	0.67	47.71	0.00	0.00	47.71	0.92
24/5	77.56	100.00	0.76	59.25	0.00	0.00	59.25	1.14
3/6	82.63	100.00	0.86	71.14	0.00	0.00	71.14	1.37
13/6	86.58	100.00	0.96	82.95	0.00	0.00	82.95	1.60
23/6	89.30	100.00	1.04	92.91	0.00	0.00	92.91	1.79
3/7	90.72	100.00	1.05	95.25	0.00	0.00	95.25	1.84
13/7	90.78	100.00	1.05	95.32	0.00	0.00	95.32	1.84
23/7	89.49	100.00	1.05	93.97	0.00	0.00	93.97	1.81
2/8	86.89	100.00	1.05	91.24	0.00	0.00	91.24	1.76
12/8	83.07	100.00	1.05	87.22	0.00	0.00	87.22	1.68
22/8	78.13	100.00	1.05	82.04	0.00	0.00	82.04	1.58
1/9	72.24	100.00	1.05	75.85	0.00	0.00	75.85	1.46
11/9	65.56	100.00	1.04	68.32	0.00	0.00	68.32	1.32
21/9	58.33	100.00	0.99	57.88	0.00	0.00	57.88	1.12
1/10	50.76	100.00	0.94	47.55	0.00	0.00	47.55	0.92
11/10	43.09	100.00	0.88	37.98	0.00	0.00	37.98	0.73
21/10	3.89	100.00	0.85	3.31	0.00	0.00	3.31	0.64
Total	1516.24			1318.90	71.49	66.67	1265.10	[1.06]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-9 Crop water requirement report for tomato

Crop Water Requirements Report

- Crop # 1 : Jui-Nuw Tomato
- Block # : [All blocks]
- Planting date : 3/4
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
3/4	41.12	100.00	0.60	24.67	11.83	11.09	13.59	0.26
13/4	48.89	100.00	0.60	29.33	8.53	8.16	21.18	0.41
23/4	56.60	100.00	0.60	33.96	4.80	4.72	29.25	0.56
3/5	64.01	100.00	0.63	40.57	0.71	0.71	39.86	0.77
13/5	70.88	100.00	0.72	51.35	0.00	0.00	51.35	0.99
23/5	77.00	100.00	0.82	62.83	0.00	0.00	62.83	1.21
2/6	82.17	100.00	0.91	74.57	0.00	0.00	74.57	1.44
12/6	86.24	100.00	1.00	86.16	0.00	0.00	86.16	1.66
22/6	89.09	100.00	1.09	97.16	0.00	0.00	97.16	1.87
2/7	90.64	100.00	1.15	104.15	0.00	0.00	104.15	2.01
12/7	90.83	100.00	1.15	104.46	0.00	0.00	104.46	2.02
22/7	89.68	100.00	1.15	103.13	0.00	0.00	103.13	1.99
1/8	87.21	100.00	1.15	100.29	0.00	0.00	100.29	1.93
11/8	83.50	100.00	1.15	96.03	0.00	0.00	96.03	1.85
21/8	78.67	100.00	1.15	90.47	0.00	0.00	90.47	1.75
31/8	72.86	100.00	1.15	83.79	0.00	0.00	83.79	1.62
10/9	66.26	100.00	1.15	76.20	0.00	0.00	76.20	1.47
20/9	59.07	100.00	1.11	65.52	0.00	0.00	65.52	1.26
30/9	51.52	100.00	0.99	51.21	0.00	0.00	51.21	0.99
10/10	43.86	100.00	0.88	38.49	0.00	0.00	38.49	0.74
20/10	7.86	100.00	0.81	6.33	0.00	0.00	6.33	0.61
Total	1437.97			1420.68	25.88	24.67	1396.01	[1.33]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table D-10 Crop water requirement report for onion

```
********************************************************************************

- Crop  # 1              : Jui-Nuw Onion
- Block #                : [All blocks]
- Planting date          : 5/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 60%
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
5/3	20.62	100.00	0.70	14.44	16.83	15.45	0.00	0.00
15/3	27.12	100.00	0.70	18.98	15.92	14.65	4.33	0.08
25/3	34.29	100.00	0.70	24.00	14.16	13.12	10.88	0.21
4/4	41.89	100.00	0.70	29.32	11.54	10.82	18.50	0.36
14/4	49.67	100.00	0.73	36.27	8.17	7.83	28.44	0.55
24/4	57.36	100.00	0.78	44.98	4.42	4.36	40.62	0.78
4/5	64.73	100.00	0.84	54.23	0.44	0.44	53.79	1.04
14/5	71.53	100.00	0.89	63.77	0.00	0.00	63.77	1.23
24/5	77.56	100.00	0.94	73.32	0.00	0.00	73.32	1.41
3/6	82.63	100.00	1.00	82.55	0.00	0.00	82.55	1.59
13/6	86.58	100.00	1.04	90.45	0.00	0.00	90.45	1.74
23/6	89.30	100.00	1.05	93.77	0.00	0.00	93.77	1.81
3/7	90.72	100.00	1.05	95.25	0.00	0.00	95.25	1.84
13/7	90.78	100.00	1.05	95.32	0.00	0.00	95.32	1.84
23/7	89.49	100.00	1.05	93.97	0.00	0.00	93.97	1.81
2/8	86.89	100.00	1.05	91.24	0.00	0.00	91.24	1.76
12/8	83.07	100.00	1.05	87.22	0.00	0.00	87.22	1.68
22/8	78.13	100.00	1.05	82.04	0.00	0.00	82.04	1.58
1/9	72.24	100.00	1.04	74.79	0.00	0.00	74.79	1.44
11/9	65.56	100.00	0.94	62.02	0.00	0.00	62.02	1.20
21/9	58.33	100.00	0.84	49.35	0.00	0.00	49.35	0.95
1/10	26.34	100.00	0.77	20.29	0.00	0.00	20.29	0.78
Total	1444.83			1377.57	71.49	66.67	1311.92	[1.18]

```
* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
********************************************************************************
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APPENDIX E

Irrigation Scheduling sample reports

- Crop # 1 : Mungbean-Jui-Nuw
- Block # : 1
- Planting date: 20/6

* Soil Data:

- Soil description : Clay
- Initial soil moisture depletion: 50%

* Irrigation Scheduling Criteria:

- Application Timing:
  Irrigate each 10days.
- Applications Depths:
  Variable depths (user-defined).
- Start of Scheduling: 20/6

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)	User Adj. (mm)
20/6	90.0	40.5	0.0	0.0	1.6	90.9%	46.6	0	17.7	0.0	
30/6	101.1	45.5	0.0	0.0	1.8	100.0%	46.6	10	18.1	0.0	
10/7	112.2	50.5	0.0	0.0	2.1	100.0%	46.9	10	12.6	0.0	
20/7	123.3	55.5	0.0	0.0	3.9	97.5%	67.3	10	22.0	0.0	
30/7	134.4	60.5	0.0	0.0	4.2	83.2%	92.9	10	30.7	0.0	
9/8	145.6	65.5	0.0	0.0	3.8	66.4%	114.5	10	27.4	0.0	
19/8	150.0	67.5	0.0	0.0	2.4	47.3%	130.5	10	26.3	0.0	
29/8	150.0	67.5	0.0	0.0	1.7	35.4%	135.0	10	24.5	0.0	
8/9	150.0	67.5	0.0	0.0	1.5	31.4%	135.9	10	74.4	0.0	
18/9	150.0	67.5	0.0	0.0	3.3	72.6%	115.0	10	66.6	0.0	
28/9	150.0	67.5	0.0	0.0	3.7	84.8%	104.2	10	53.5	0.0	
8/10	150.0	67.5	0.0	0.0	2.6	89.1%	96.3	10	26.7	0.0	
18/10	150.0	67.5	0.0	0.0	1.0	85.7%	90.3	10	4.3	0.0	
Total			0.0	0.0	448.0	65.4%			404.8	0.0	0.0

* Yield Reduction:

- Estimated yield reduction in growth stage # 1 = 0.1%
- Estimated yield reduction in growth stage # 2 = 25.4%
- Estimated yield reduction in growth stage # 3 = 34.8%
- Estimated yield reduction in growth stage # 4 = 3.2%

- Estimated total yield reduction = 39.8%

* These estimates may be used as guidelines and not as actual figures.

APPENDIX F

QUESTIONNAIRE SURVEY

Research Title: Improving Irrigation Water Allocation and Use in Arid and Developing Context
Researcher: Ahmad Faisal Basiri
Institute: Asian Institute of Technology

PART.I

1. Location (Herat province of Afghanistan)
   Latitude (   ), longitude (   ), Altitude (   )
2. Farmer's Name…………………………………………………………………
3. House hold Size……………………………..

PART.II

4. Total size of farm …………………………………………………………..(.ha)
5. Type of irrigation and source of irrigation. ………………………………………..

How much water is given from the canal for different Crops in different season?

Type of Crop		Cultivated Area Jarib (2000 m^2)	Crop season			Planting Date	Harvesting Date	Irrigation Schedule			Soil Type	Canal size					Water Shortage months	
													Water depth (cm)					
First Crops	Second Crops		Winter	Spring	Summer			Irr interval Day	Time (hr)	# irr per season (day)		Width (cm)	spring	Summer	winter	Canal side slop	Started	Ended

Yield, Production cost, yield reductions, and no water restriction time

Plot No	Yield Kg/jarib	Market Price Afg/kg	Production cost										Yield reduction causes					Months which are no water restriction in the canal	
			Fertilizer		Labor		Machine		Irrigation		Seed								
			Cost Afgs	Kg/Jarib	Cost Afgs	Per/Jarib	hr/Jarib	Cost Afgs	Times/Jarib	Cost Afgs	Cost Afgs	Kg/ jerib	Water Shortage	Diseases	Weather	Soil	Land leveling	Started time	Ended time
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			

6. Return Period of each crop
7. Is the available amount of water is enough for your crops?

Yes	No

8. Is current Scheduling is suitable for your Irrigation?

Yes	No

9. What are the alternative crops that you can cultivate during water shortage period?
10. Which crops are more profitable? ....

(Thanks for your Kind Information)